

REPORT
ON
THE BUILDING STONES
OF THE
UNITED STATES,
AND
STATISTICS OF THE QUARRY INDUSTRY
FOR 1880.

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EXPORTATION OF STONE

IMPORTATION OF STONE INTO THE UNITED STATES

Tables showing imports and exports of marble and stone, by countries, for the year ending June 30, 1881

EGYPTIAN BRECCIA

CHLORITE ROCK

ALGERIAN ALABASTER

ITALIAN MARBLE (CARRARA)

Statement of the exportation of marble from the consular district of Carrara in the year 1879

Statement of the exportation of all kinds of marble from 1872 to 1879

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* Plate LV: for *Maryland*, read “Missouri”.

LETTER OF TRANSMITTAL.

WASHINGTON, D. C., *February 19, 1883.*

Hon. CHARLES W. SEATON, *Superintendent of Census.*

SIR: In accordance with your request, I have examined and revised the following report upon the building stones and quarry industries of the United States.

This work was undertaken jointly by the Census Office and the National Museum, and placed in charge of the late Dr. George W. Hawes, then curator of the department of mineralogy and lithology in the National Museum.

The work as planned by him comprised the collection of very full and complete statistics from all quarries in the United States doing business during the census year to the extent of \$1,000, and the making of a collection of quarry specimens for examination for the purpose of this report and for deposit in the National Museum as a reference collection. These plans contemplated also a thorough study of the building stones with reference to their hardness, durability, beauty, chemical composition, microscopic structure, and geological relations. Dr. Hawes lived long enough to see his plans well under way, the collection practically completed, and much of the microscopic and chemical work done. His health failed in the fall of 1881, and he was obliged to give up work, when his principal assistant, Mr. F. W. Sperr, was placed in temporary charge. Dr. Hawes' health continued to fail, and at last, on June 22, 1882, he died, at Colorado Springs, Colorado.

Not long after, Mr. Sperr's health failed, and he was obliged to give up the control of the work, when it was left in charge of Mr. Thomas C. Kelly, by whom it was brought to its present stage.

As assistants in the field-work of this investigation Dr. Hawes enlisted the services of many of the most prominent geologists and mineralogists of the country, and to them is due in great measure whatever success may have been attained in this investigation. They have devoted to it much valuable time and attention, and in every way have shown the utmost interest in prosecuting it thoroughly. Many of these gentlemen have also rendered valuable services in furnishing manuscript notes regarding the quarries of their respective districts, which, from the local knowledge of the author, is of great value. The statistics and the information concerning the quarries were gathered by the following gentlemen in the areas indicated:

In Maine, Rhode Island, and that portion of Massachusetts east of the Connecticut river, Professor N. S. Shaler, of Harvard university, Cambridge, Massachusetts.

In New Hampshire, Vermont, and that portion of Massachusetts west of the Connecticut river, and of New York east of the Hudson and above the latitude of the north line of Connecticut, Professor O. H. Hitchcock, of Dartmouth college, Hanover, New Hampshire.

In Connecticut, and New York east of the Hudson and south of the latitude of the north line of Connecticut, Mr. Harrison R. Lindsley, of New Haven, Connecticut.

In Manhattan Island and cities in the immediate vicinity of New York, Professor Alexis A. Julien, of the School of Mines, Columbia college, New York city.

In the portion of New York west of the Hudson, and New Jersey outside of the immediate neighborhood of New York, Professors George H. Cook, director of the geological survey of New Jersey, and James C. Smock, of New Brunswick, New Jersey.

LETTER OF TRANSMITTAL.

In Pennsylvania, Mr. Charles Allen, of Harrisburg, Professor J. P. Lesley, state geologist, and Messrs. Ashburner, Lehman, D'Invilliers, and other members of the second geological survey of that state, and Messrs. F. W. Sperr and Thomas C. Kelly.

In Maryland, Delaware, and Virginia, Professor J. H. Huntington, Boston, Massachusetts, Professor Charles E. Munroe, United States Naval Academy, and Mr. H. K. Singleton, of Mississippi.

In Ohio and Indiana, Professor Edward Orton, Columbus, Ohio.

In Kentucky, Professor J. R. Procter, state geologist, Frankfort, Kentucky.

In Michigan, Wisconsin, and Illinois, Professor Allen D. Conover, Madison, Wisconsin.

In Minnesota, Iowa, and Dakota, Professor N. H. Winchell, state geologist of Minnesota, Minneapolis, Minnesota, and Mr. W. J. McGee, Farley, Iowa.

In Missouri and Kansas, Professor G. C. Brodhead, state geologist of Missouri, Pleasant Hill, Missouri.

The statistics in the southern states were collected by Mr. Henry B. Cotton and Dr. A. Gattinger, of Nashville, Tennessee, and those of the west by Mr. William Foster, of Denver, Colorado.

A number of assistants, who also rendered much valuable service, was employed by the gentlemen above mentioned. In addition to the above list of regular assistants upon this work, a great many persons aided in extending the scope of the work, especially by bringing to notice some of the great undeveloped resources of the country.

The unfortunate death of Dr. Hawes necessitated a considerable change in the character of the report. It became necessary to curtail what might be called the scientific portion, that relating more purely to lithology, thus giving greater relative prominence to the economic side of the subject. With this exception the original plans of Dr. Hawes have been carried out as far as possible.

The following is a sketch of the topics under which the report is arranged:

Following the introduction, which consists of the discussion of general matters relating to the subject, are tables showing the number of quarries, the capital invested in them, product in the census year, and its value, and other details regarding labor, means of transportation, etc. These tables are given by states and by general classes of rocks, and form a general exhibit of the extent of the quarry business in the country. The quarries of each state which is of importance in this respect are then taken up in detail, the general facts regarding the individual quarries being given in tabular form, with location, kind of rock, structure, quality, color, geological formation, etc. Descriptive text follows each table, and is intended to fill out and complete the matter in the tables in such a way as to give the details which are desirable to be known regarding the quarries of importance. Then follow a description of the use of stone in most of the principal cities of the country, the extent to which it is employed, the kinds of stone principally used, and other matters of importance connected with this subject. This description is accompanied by a table showing the proportion of stone buildings in each city, the class of stones principally used, and their sources, and the stone employed for foundations, pavements, etc. A short table of exports and imports of stone and a brief discussion of a few notable foreign ornamental stones close the report.

In the following report it will be observed that a comparatively small portion of the work bears the name of Dr. Hawes as author, but the amount of this matter must not be taken as in any way the measure of the share which he had in the work. Not only are the inception and plan of the entire work due to him, but a large proportion of the material from which this manuscript was made was collated and drafted roughly by him, though not put in shape for publication. He plowed, sowed, and cultivated that others might reap.

The chemical work of the report and the classification of the limestones were done by Mr. F. P. Dewey, of the Smithsonian Institution, and his report upon the general methods employed by him is included in the introductory matter.

The microscopic examination of the rocks commenced by Dr. Hawes was completed by Mr. G. P. Merrill, of the Smithsonian Institution, and his report upon this subject also is included in the introductory matter.

The illustrations of polished rock surfaces, representing some of our most beautiful and serviceable rocks, were drawn in water color by Mr. Henry J. Morgan.

The chapter upon methods of quarrying, machines, and tools used in such operations was prepared by Mr. F. W. Sperr.

The great bulk of the text, consisting of descriptions of the quarry regions and individual quarries, and of the use of stone in construction in the principal cities of the country, was in the main compiled by Messrs. Sperr and

Kelly from descriptive notes furnished by the different special agents enumerated above. The degree of fullness of these notes depends, therefore, not so much upon the importance of the quarry industries in the different districts as upon the extent of the descriptive matter furnished by the different special agents; and it is doubtless true that undue prominence has on this account been given to certain regions. For example, the quarries of the state of Ohio have been described in great fullness of detail, while the marbles of Tennessee receive but a passing mention. It does not, however, appear to be advisable to throw away a large part of this information for the mere sake of producing uniformity.

The notes of Professor Shaler regarding his district are so full and elaborate that it has been thought best to present them, with little change, over his own name. The same is the case with those for Illinois, Wisconsin, and Michigan, by Professor Conover; for Iowa, by Mr. W. J. McGee, and a portion of the notes concerning Missouri, by Professor Brodhead, the state geologist.

In the chapter upon stone construction in cities New York city is treated exhaustively by Professor A. A. Julien, who in addition to this furnished a paper on the very important subject of the durability of the building stones in actual use in the country.

It should be borne in mind that the statistical tables deal in general only with quarries which produced during the census year to the value of \$1,000 or upward. This excludes not only a large number of small quarries, but also many which have in years past produced very extensively, but which were worked little or not at all during the census year.

Nearly all the quarries of the southern states, with the exception of the marble quarries of Tennessee, fall within one or the other of these classes. For instance, out of a large number of quarries in North Carolina, scarcely one, under the above definition, should be represented in the tables.

In this portion of the country this industry is yet in its infancy. The slight demand for stone in construction, owing to the relative cheapness of other building material, especially wood, and the fact that the region contains but a small urban population, have combined to delay its development, and to-day the south is but beginning to realize its immense resources of this kind.

The reader will doubtless find in the text, and especially in that portion relating to stone construction in cities, many references to quarries which are not represented in the tables. These apparent omissions, in the majority of cases, fall into one or the other of the above classes of intentional omissions, that is, of quarries whose importance is not sufficiently great to give them place in the statistical tables, or where the quarries, although large and important, are worked spasmodically, as occasion requires, and were not worked extensively during the census year. Still, as this is practically the first attempt which has ever been made to obtain the statistics of this industry, it is very possible that some important quarries have escaped notice, although every precaution for obtaining completeness which had suggested itself to those having the matter in charge was taken. Wherever practicable, the local knowledge of the state geologists, and of others more or less directly interested in this industry, was utilized, and it is believed that, under the circumstances, the omissions have been reduced to as small a quantity as possible.

Very respectfully, yours,

HENRY GANNETT,
Geographer and Special Agent Tenth Census.

THE BUILDING STONES OF THE UNITED STATES AND STATISTICS OF THE QUARRY INDUSTRY.

CHAPTER I.—INTRODUCTION.

BY DR. GEORGE W. HAWES.

Materials for building may be divided into two classes, natural and artificial. Of the former class may be mentioned, as the principal members, wood and stone, and of the latter class, brick, artificial stone, and iron. The industry of extracting stone for building purposes has been, for convenience in this report, denominated the quarry industry. This term is not accurately descriptive, since all the materials extracted from quarries or open mines are not here described. Coal, metallic ores, limestone when quarried for lime or for fertilizing, and phosphate of lime when quarried for the latter purpose, may be noted as exceptions.

The importance of this investigation will be recognized when it is known that the subject has received little or no attention heretofore in this country, although immense sums are spent annually upon stone as a material in construction.

The first, and indeed the only attempt, so far as known, to bring into notice our resources in building stone was made at the late centennial exposition at Philadelphia, when a general invitation was sent to quarrymen to forward specimens for exhibition. This was generally responded to, and a beautiful collection was the result; but it was by no means exhaustive or representative, inasmuch as it was a purely voluntary collection.

Many experiments upon the strength of building stone have been made, notably by the officers of the United States engineer corps, and the results, published only in a fragmentary way, are more or less inaccessible. Strength, however, is but one of the factors which determine the relative value of the stone. The factor, primarily, is its accessibility, as the most valuable stone is of but little use for extensive building operations if far from water or railroad transportation. Next in importance is its durability, as well as its capability of resisting climatic influences; and this is a subject upon which very little has been said or written. It is a subject upon which it is extremely difficult to experiment, and yet in this respect it is most desirable that we should possess information. Such knowledge can be gained only by experience, and in many cases dearly-bought experience, and it is therefore important that all facts relating to the durability of stone under the influences of climate should be collated and brought into juxtaposition with one another.

THE COLLECTION.

The considerations already advanced show the desirability, in connection with a work of this kind, of making a systematic collection of specimens of building stones. The popular names given to building stones vary in different parts of the country, and the same name is in some cases applied to most diverse materials. Such words as granite, trap, blue-stone, flag-stone, etc., do not designate stones in such a manner as to enable one to judge of their appearance or characteristics, and, beyond its necessity for purposes of classification, a collection is of such value to architects and builders as to justify its accumulation at government expense. At the centennial exhibition in Philadelphia in 1876 many of our best stones were placed in direct comparison with those from foreign countries, and visitors were surprised to find that our country possessed materials for which we have been in the habit of looking to other lands. This collection was made the subject of a report by Professor J. F. Newberry, of the School of Mines, Columbia College, New York city, which report forms one of the most prominent contributions to the literature upon the general resources of the country in stone.

This collection, however, did not claim to be either systematic or complete. The Census Office has aimed at system and uniformity in the collection and treatment of specimens, in order to insure fair comparison. The size of the specimens was determined by such considerations; it having been the intention that every quarry of importance in the country should be represented in the collection by a cube with edges four inches long. These specimens are dressed in the following manner:

Polished in front.

Drafted and pointed on the left-hand side.

Drafted with rock-face upon the right-hand side.

Entirely rough behind.

Rubbed or chiseled upon top and bottom.

The aim has been to show the appearances of the stone when subjected to such treatment as it will receive when applied to construction and ornamentation. The polished surfaces render prominent many peculiarities of structure and composition which are not evident upon rough surfaces. The only modification that has been allowed has been in the treatment of the front face, which, when incapable of being polished, has received the highest finish which it can be made to receive.

The specimens are of such size as to admit of easy handling and close examination, and are easily accessible to all interested in their study and comparison. The centennial collection has been united with these, and the whole forms one of the attractive features of the National Museum in Washington.

A number of treatises upon building material have been issued in European countries, and the crudeness of their statements concerning the quarries of America is most striking when one notes the size of this collection and the diversity of its specimens. The statements, however, are not to be wondered at, since the authors have had little accessible American literature. It might, however, be assumed that a country of this extent, possessing so great diversities in physical features, would possess a great variety of building stones.

It may be said in general that at this stage of the development of the stone industry in the country there are few quarries which do not produce material possessing something or other to recommend them and to give them an excuse for existing. This can scarcely be otherwise in a land which possesses such an immensity of undeveloped resources in stones of the finest quality.

The collection, however, brings one thing most prominently forward, and that is that at the very doors of buildings constructed of stones brought from great distances materials equal or superior are often found. The lack of confidence in home resources has very frequently caused stones of demonstrated good quality to be carried far and wide, and frequently to be laid down upon the outcropping ledges of material in every way their equal. Development of local resources follows in the wake of good information concerning them, for the lack of confidence in home products cannot be attributed to prejudice. The first stone house erected in San Francisco, for example, was built of stone brought from China, and at the present day the granites mostly employed there are brought from New England or from Scotland. Yet we have no stones in our collection possessing more qualities to recommend them than California granites.

Some of the results of this general ignorance of the resources that this country affords in the way of building stones is shown by the use of stones brought from the Atlantic sea-board in the public buildings of the Mississippi valley. Some of the prominent public and private buildings in Cincinnati, for instance, are constructed of stone that was carried by water and railway a distance of about 1,500 miles. Within 150 miles of Cincinnati, in the sub-Carboniferous limestone district of Kentucky, there are very extensive deposits of dolomitic limestone that afford a beautiful building stone, which can be quarried at no more expense than that of the granite of Maine. Moreover, this dolomite is easily carved; it requires not more than one-third the labor to give it a surface that is needed by granite. Experience has shown that the endurance of this stone under the influences of weather is very great. A building in Bowling Green, Kentucky, which has been standing over forty years, retains the chisel marks with all the clearness they had the day they were made. Yet, because of the want of some authority of an absolute sort, the fear to use this stone has so far kept it from finding a market and has led to the transportation of stone half-way across the continent.

In all other mining industries the product shows the fitness for its use almost at the moment of its production, so that, if the government secures the exercise of proper precaution in the carrying on of the work, the character of the products may be left to be determined by the laws of trade. But in building stones there is always the question of endurance under the action of the weather, which cannot be determined in any easy way. The external aspect of the stone may fail to give any clue to it; nor can all the tests we yet know determine to a certainty in the laboratory just how a given rock will withstand the tests of absorption of our own variable climate and the gases of our cities. The cities of northern Europe are full of failures in the stones of important structures. The most costly building erected in modern times, perhaps the most costly edifice reared since the great pyramid, the parliament-house in London, was built of a stone taken on the recommendation of a committee representing the best scientific and technical skill of Great Britain. The stone selected was submitted to various tests, but the corroding influence of a London atmosphere was overlooked. The great structure was built, and now it seems questionable whether it can be made to endure as long as a timber building would stand, so great is the

effect of the gases of the atmosphere upon the rock. This is only one of the numerous instances that might be cited in which a neglect to consider the climatic conditions of a particular locality in selecting a building material has proved disastrous. Stones having a high ratio of absorption, or which absorb water readily, are not likely to be durable in a climate subject to alternations of dampness and hard freezing; and, as before mentioned, the acid atmosphere of manufacturing cities is injurious to stones made up largely of carbonate of lime. Professor Hull, in his work on the building and ornamental stones of Great Britain and foreign countries, gives the following as the most instructive examples of "buildings in Great Britain of limestones and dolomites which have shown disintegration from the influence of rain charged with acid: Saint Mary's, Redcliffe, in Bristol; the new houses of parliament, and the chapel of Henry VIII in Westminster Abbey. The first is built of oolitic limestone, the second of dolomite, the third of Caen stone, the white limestone of Normandy, of Jurassic age". Professor Hull states further that the presence in humid or wet climates of smoke, or sulphurous, hydrochloric, and other acids, powerfully aids the destructive effects of rain or moisture, as the rain itself takes a considerable amount of the acid from the air and spreads it over the exposed surfaces of the buildings; and that, therefore, for such climates limestone of especially soft, granular, and porous kinds should as far as possible be avoided; also, sandstones which contain a notable percentage of calcareous matter in the form of cement should not be used.

Some of the "black granite" or diabase rocks of New England decay rapidly when exposed to the weather, yet they are, in appearance, of enduring quality.

In a communication to the Census Bureau, Professor N. S. Shaler, of Cambridge, Massachusetts, says:

A few years ago I found the stone from one of these diabase quarries being used for the foundations of the most costly buildings ever erected by Harvard college. A century of exposure would be sure to convert a large part of the faces of these foundation stones into dry sand. It was by a mere chance that I was able to make an effective protest against its use in this building. I know that it has been used in scores of other buildings in the same region.

There are many other stones in use in this country that are open to the same objections; they are fair looking, but have not the necessary endurance, under certain atmospheric conditions, which makes them fatal elements of weakness in any architectural work of importance.

It is not possible for the architect or the builder to make tests and accumulate information concerning the particular qualities of this or that stone; nor is it possible for any association such as the national societies of architects to do justice to the problem. The result is that it is very hard to bring a new quarry stone into use unless it is essentially like some of those already extensively employed. No one builder is willing to assume the risk that may come from the experiment, especially when he is not likely to have the profit that may arise from the use of the cheaper stone. There can be no question that in this way we are debarred from the use of many of the best and cheapest building stones that the country affords. Professor Shaler advises substantially the following plan:

In proposing to myself a method whereby a source of necessary information concerning the building stones of the country may be established, I have taken care to make the element of interference on the part of the state as small as possible. It seems to me that the following plan may serve to accomplish the end in view without undue expenditure or overregulation. There should in the first place be a national collection of building stones whereat the architect may be able to see a sufficient representation of all the building stones the country affords.

The admirable system followed by the Tenth Census has already accumulated at Washington an excellent foundation for such a collection. By the simple plan of having large specimens of the stones heretofore used in all public buildings added to this collection, and further by letting it be known that architects would confer a favor by submitting specimens of the stone used by them, a very valuable collection could be accumulated. In addition to this interior cabinet there should be an open-air collection designed to show the effects of weathering upon the various classes of building materials. This collection would necessarily occupy a good deal of ground, for in many cases several courses of stone, one on top of the other, would be necessary to show the full effect of weathering. The attitude of the wall with reference to the sun, frost, etc., is a matter of importance. It should also include water-cement, roofing materials, and various forms of terra-cotta, from common brick to decorative work. In fact such a collection should be essentially an experimental station on construction materials.

With the view of accomplishing more perfectly the large purposes that could only be accomplished by such a museum, I would suggest that the whole matter of strength of materials used in public edifices should be placed in the control of its superintendent; and that, on the payment of a small fee, the laboratory connected with the museum might examine into the composition and character of building material submitted to it. Each subsequent decennial census will give a chance to revise and extend the researches of this museum.

In addition to the ordinary specimens of building stones, quarry-owners were invited to represent their material in the National Museum by a larger specimen, dressed by themselves and forwarded at their own expense. To this invitation many quarrymen have responded by sending dressed foot cubes or slabs, pedestals, etc., many of which are very beautiful. We have not allowed the prominence thus given to individual quarries to modify or prejudice our opinion of the material. No injustice has thus been done, as no effort was made to gather these blocks, and any one had, and still has, the opportunity, if he wishes, to supplement his exhibition with such blocks. Our 4-inch cubes are, however, to us the most satisfactory specimens, as showing the nature of the material and forming a systematic collection which it would be impracticable to attempt to make of larger blocks.

One of the large halls in the National Museum at Washington has been set apart for the exhibition of this census collection of building and ornamental stones, and no trouble has been spared by the authorities in the attempt to show each specimen to the best advantage. They are placed in glass cases, in front of a suitable background; each rests on a block, and a card designating the stone and the features of particular interest in connection with it is tacked upon this block, where it can be easily read.

The centennial collection before mentioned, or so much of it as was presented to the Smithsonian Institution, is placed in the hall. The addition which it has made to the census collection is mostly composed of foreign stones.

The supervising architect of the treasury, Mr. Hill, has also kindly given a large portion of the collection which has accumulated in his office, to be used in the study and in supplementing the collection.

THE MINERALS IN BUILDING STONES.

A stone is of little consequence for purposes of construction unless it exists in large quantities, and therefore the principal constituents are the commonest of minerals and few in number. Microscopic examination increases the number of the species quite considerably, and at times those present in smallest amount are of great importance in the determination of economic properties. As these minerals are sufficiently described in any mineralogical treatise, it is only necessary to mention the names of those which occur in building stones.

The mineral compositions of stones are much simplified by the wide range of conditions under which the commonest minerals can be found, thus allowing their presence in all classes of rocks. Thus quartz, feldspar, mica, hornblende, and pyroxene can be found in a mass cooling from a state of fusion; they can be crystallized from solution, or be formed from volatilized products. They are, therefore, excluded from no classes of rocks, since there is no process of rock formation which determines their absence.

Most of the commonest minerals, like feldspar, mica, hornblende, pyroxene, and the alkaline carbonates, possess also the capacity of adapting themselves to a wide range of compositions. Feldspar, for example, can take more or less silica, lime, soda, or potash into its composition. Hornblende and pyroxene may be pure silicates of lime and magnesia, or iron and manganese may take the place of a portion of these bases. Lime carbonate may be very pure, or magnesia may take the place of any proportion of the lime.

These considerations indicate the reason of the extreme simplicity of rocks as regards their chief constituents, and that whatever may be the composition of a mass within the limits which nature allows, and whatever may be the conditions of its origin, the probabilities are that it will be essentially formed of one or more of a half dozen minerals in some of their varieties.

But, however great may be the adaptability of these few minerals, they still are subject to very definite laws of chemical equivalence; there are elements which they cannot take into their composition, and there are circumstances which retard their formation while other minerals are crystallizing. Therefore, in a mass of more or less accidental composition, other minerals may always be expected to form in considerable numbers and minute quantity.

For convenience we may therefore divide the minerals into two groups: the first to contain those minerals with their varieties which compose the mass of rocks, and any one of which may be the chief ingredient of a rock; and the second to contain those which never compose the mass of a building stone, and are, when present at all, usually present in small amount.

The following is a list of the mineral constituents of most building stones:

1. Quartz.

2. Feldspar.

2a. Orthoclase.

2b. Microcline.

2c. Albite.

2d. Anorthite.

2e. Labradorite.

2f. Andesite.

2g. Oligoclase.

2h. Triclinic feldspar (undetermined species).

3. Mica.

3a. Muscovite.

3b. Biotite.

3c. Phlogopite.

3d. Lepidolite.

4. Amphibole or hornblende.

4a. Tremolite.

4b. Actinolite.

4c. Common hornblende.

5. Pyroxene.

5a. Malacolite.

5b. Sahlite.

5c. Diallage.

5d. Augite.

6. Calcite.

7. Dolomite.

8. Serpentine.

9. Talc.

ELEMENTS.

10. Iron.

11. Copper.

12. Carbon.

13. Graphite.

SULPHIDES.

14. Galenite. (Lead glance.)

15. Sphalerite. (Zinc-blende.)

16. Pyrrhotite. (Magnetic pyrites.)

17. Pyrite. (Pyrites.)

18. Chalcopyrite. (Copper pyrites.)

19. Marcasite. (White pyrites.)

20. Arsenopyrite. (Mispickel, or arsenical pyrites.)

CHLORIDE.

21. Halite. (Common salt.)

FLUORIDE.

22. Fluorite. (Fluor-spar.)

OXIDES.

23. Tridymite.

24. Opal.

25. Corundum. (Emery.)

26. Hematite. (Specular iron.)

27. Menaccanite. (Titanic iron.)

28. Magnetite. (Magnetic iron.)

29. Chromite. (Chromic iron.)

OXIDES—continued.

- 30. Limonite. (Hydrous iron oxide, rust.)
- 31. Spinel.
- 32. Rutile.
- 33. Pyrolusite. (Manganese binoxide.)

ANHYDROUS SILICATES.

- 34. Enstatite.
- 35. Hypersthene.
- 36. Acmite.
- 37. Glaucophane.
- 38. Beryl.
- 39. Chrysolite. (Olivine.)
- 40. Danalite.
- 41. Garnet.
- 42. Zircon.
- 43. Epidote.
- 44. Allanite.
- 45. Zoisite.
- 46. Iolite. (Cordierite.)
- 47. Scapolite.
- 48. Elacolite.
- 49. Sodolite.
- 50. Cancrinite.
- 51. Chondrodite.
- 52. Tourmaline.
- 53. Andalusite.
- 54. Fibrolite.
- 55. Cyanite.
- 56. Topaz.
- 57. Datolite.
- 58. Titanite. (Sphene.)
- 59. Staurolite.

HYDROUS SILICATES.

- 60. Petalite.
- 61. Laumontite.
- 62. Prehnite.
- 63. Thomsonite.
- 64. Natrolite.
- 65. Analcite.
- 66. Chabazite.
- 67. Stilbite.
- 68. Heulandite.
- 69. Harmotome.
- 70. Kaolin.
- 71. Chlorite.
- 71a. Jeffersonite.
- 72. Ripidolite.
- 73. Penninite.
- 74. Prochlorite.

PHOSPHATE.

- 75. Apatite.

SULPHATE.

- 76. Gypsum.

CARBONATES.

- 77. Aukerite.
- 78. Siderite.
- 79. Rhodochrosite.
- 80. Aragonite.
- 81. Malachite.
- 82. Azurite.

METHODS OF STUDY.

The methods usually applied to the study of building materials are eminently practical. The required qualities of good stones are well understood, and direct processes are employed in order to ascertain the strength, hardness, and durability. Experience most of all has aided in the development of knowledge, and this sometimes has been gained at great expense. Though the results of actual practice are the final criterions, they are too slowly gained, and hence scientific and practical study can be combined to the advantage of those using stone.

On the other hand, the application of scientific methods to economic problems, while bringing the later results of study into the domain of daily life, has never been carefully performed without incidentally developing some things of interest and value to science. There are no absolute rules to lay down by which stones are to be judged, however simply such are recorded in the text-books.

Stones which have lain in the quarry for years, and which show the effects which time can produce, are usually inferior specimens that have been rejected, and quarries which have produced bad materials may also subsequently produce the best, and *vice versa*.

The methods which have been employed in the study of compositions and structures are, however, such as require some explanation.

The purposes of the work demand a determination of the compositions and structures of the various rocks, as these in combination with the location and geological features determine the applicability of the stones and explain their peculiar properties. The microscopic examination of thin sections leads most directly to the desired results. This method of study in the hands of the microscopic lithologist has been most fruitful in developing valuable and interesting knowledge of a scientific character. By its means the nature and the composition of almost all of the commonly-occurring rocks have been determined, and geological progress in later years has been modified and directed to a certain extent by the results of microscopic study. Exactly those same features which are of importance in scientific study are the ones which determine the value and appearance of building stones; and there is no distinction between the scientific and the practical.

The method will here be described with the least detail that will render the accompanying plates comprehensible to those who are interested in the results but unacquainted with the method. Any who wish to apply the method will seek fuller information in the treatises devoted to the subject.

A thin fragment of stone with a circumference equal to that of a silver quarter-dollar is knocked from the larger block with a hammer or a pitching-tool; or when difficulties are encountered in obtaining thus a favorable

piece, the same is sawed off from the block with a diamond saw. When a flat, smooth surface has been ground upon one side of this chip, and which reaches the outer circumference of it at every point, the chip is glued firmly upon a slide of glass, by means of hot Canada balsam, in such a way that the new, smooth surface is very nearly in contact with the glass. The Canada balsam hardens on cooling, and the stone will adhere to the glass with great tenacity. The glass slide thus furnishes a support, by means of which the stone can be held in contact with a revolving disk supplied with wet emery, and ground away on the other side until it becomes thin and transparent. By means of graded emery the stone is reduced to a very thin film; a good section being less than one-thousandth of an inch in thickness; and under this treatment even the most opaque stones which are employed for building purposes become transparent. It will be seen that in a section thus prepared the film which remains is composed of sections through the components of the rock, and that its grains or crystals have been undisturbed. An examination of the section by means of the microscope will show not merely the various substances which compose it, but also the method according to which they are arranged and by which they are attached to one another. With a magnifying power the minutest inclusions can be recognized, and by the application of optical methods

the ingredients can all be determined. It is found that the stones which we ordinarily employ are much more complex in composition than once was thought, and the minerals which compose the stones are frequently different from what would be supposed by examination with the unaided eye. For the improvement and preservation of the section it is usually transferred to a new, clean slide, and covered with a thin film of glass, which is firmly fixed by gluing with Canada balsam.

The examination of thin sections has been found most useful to botanists, zoologists, and pathologists, who have long employed the method for most important examinations. The method was recommended to the mineralogists by Cordier in 1816, but neither chemical nor optical methods were then enough advanced to render its use practicable. Thin sections were made by Mr. H. Whitham in 1831, when studying the microscopic structures of fossil plants, which necessitated making thin sections of materials practically according to the method described. Mr. H. C. Sorby first applied the microscope to lithology, and discovered many facts. Since that time a score of lithologists have occupied their time in cutting sections of all possible stones, and have developed a knowledge of their compositions, structures, and features, but as a rule with strictly scientific ends in view.

THE OPTICAL EXAMINATIONS.—If sections prepared as described are placed upon the stage of the microscope, simple observation will indicate that most stones are complex; that their ingredient minerals are more or less impure; that they possess peculiarities of cleavage, fracture, and color; that in some cases they are more or less decomposed; that they are united with one another in very different ways in different cases, and that a variety of minerals is frequently present in small amount not visible to the unaided eye.

It will also be noticed that all the sections of the same minerals do not look alike, and that there is a probable difference between many which do look alike. This is especially the case in the white minerals which are present in considerable numbers in building stones, and other minerals with weak colors become white when ground so thin. In order to identify the minerals present it is necessary to use certain optical appliances which develop more individual peculiarities. When the polished surface of a stone is examined, its appearance is determined by the character of the light which it reflects. The amount of light reflected from the outer surface determines its brilliancy, the light reflected from internal surfaces imparts iridescence and reveals structure, and the light absorbed determines the color of the stone. But when a section of a stone is examined the appearance of this section depends upon the character of the light which it transmits. The colors which are reflected from a surface may be quite different from those which are transmitted by the body, and the general appearance of a section, therefore, is entirely different from that of a surface.

When light enters from a medium of one density into a medium of another density, as, for example, when it enters from the air into water, if its direction is oblique to the surface separating the two substances it is deflected toward a perpendicular to the surface. This is called refraction, and the relative amount of the deflection which

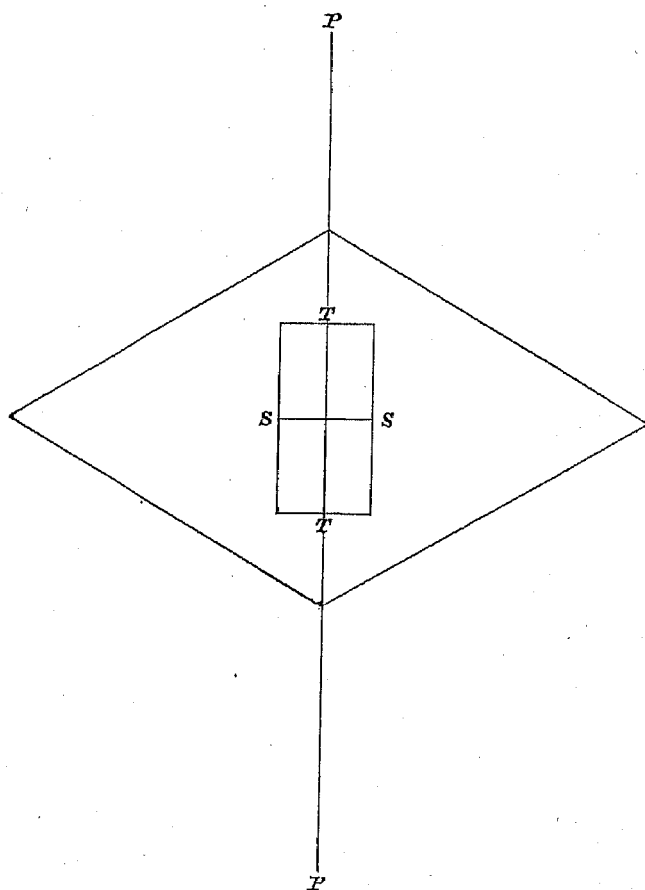


FIG. 1.

is caused when light enters different substances from the same medium is expressed by the index of refraction. Minerals possess great differences in their indices of refraction, these differences being manifested in thin sections. A mineral which possesses a high index of refraction, and which consequently deflects a beam of light to a greater degree, is apparently thicker than a mineral with a small index of refraction, since the refraction causes a retardation of the light, which is equivalent in effect to the thickening of a mineral with a less refractive index. Moreover, the surface of a section being covered with Canada balsam, the appearance of this surface is modified by the refractive properties possessed by a section. If a mineral possesses a high index of refraction there is a greater difference between its index and the index of the balsam than in the case of a mineral with a low index of refraction, and consequently its surface will appear rough, since all the asperities which this surface possesses will become evident on account of the alteration in direction and the change of velocity which will take place when the light emerges from the surface of the section. The minerals of crystalline rocks possess generally quite high indices of refraction, and the beauty of polished surfaces is much enhanced thereby. The effects of refraction are much modified by the crystalline structure of the minerals, and are dependent upon this structure.

A crystal, in the modern acceptance of the term, is a homogeneous substance, the ultimate particles of which are definitely arranged. The physical properties, such as cleavage and hardness, which are of importance in building stones, are determined by this molecular arrangement. If a crystal develops in a space surrounded by fluid or by plastic substances, it will develop into a form bounded by planes which, in position and direction, are characteristic of the substance. In rocks, as a general rule, there has been no opportunity for such crystalline development, and the substances by their mutual contact have so interfered with one another in their development as to give them forms which are arbitrary and, to a certain extent, accidental. The internal arrangement of the substances in crystalline form is, however, as perfect as if the external forms were characteristically developed. Rocks may therefore be said to be made up of crystals which, in some cases, as in porphyries, possess characteristic form, but which usually are granular and irregular in form, and are either united upon their edges or cemented together by some interposed foreign substance.

One of the fundamental properties of crystals is that the light which passes through them passes in definite directions and is submitted to definite modifications. An ordinary beam of light is composed of vibrations which differ from the vibrations of sound in that while sound is propagated by vibrations the axes of which are parallel with the direction of propagation, light is composed of vibrations which take place in all directions perpendicular to the direction of the beam. The color of a beam of light depends upon the duration of the vibration, and the intensity depends upon the amplitude. If a beam of light enters from the air into a non-crystalline structure it suffers no further modification than the simple refraction; if it enters a crystal it may pass through it as through a non-crystalline substance, or it will be modified in such a way as that the vibrations which have been stated to take place in every direction about the axis of transmission will all be reduced to two planes which are at right angles to each other and are definite in direction. As to the method in which the light is modified in passing through the crystal, that depends upon the nature of the substance and the degree of symmetry which the crystal possesses. The simplest illustration of such a modification is seen by examining a dot through a piece of the ordinary calcite or Iceland spar; the dot will appear double, and the two apparent dots will have different appearances, dependent upon the difference of refraction of the two parts of the ray, which are separated in the crystal and are vibrating at right angles to each other. If a ray of light has passed through a crystal, and has had its vibrations thus all reduced to two planes, one of the two portions of light is what is called polarized; and the effects of this kind of light can be much better observed if by means of some contrivance one of the sets of vibrations can be absorbed so that a light can be obtained, all the vibrations of which take place in a single plane. Polarized light, then, as distinguished from ordinary light, is light the vibrations of which occur in one plane instead of taking place in an indefinite number of planes, as in ordinary light. Such polarization can be effected

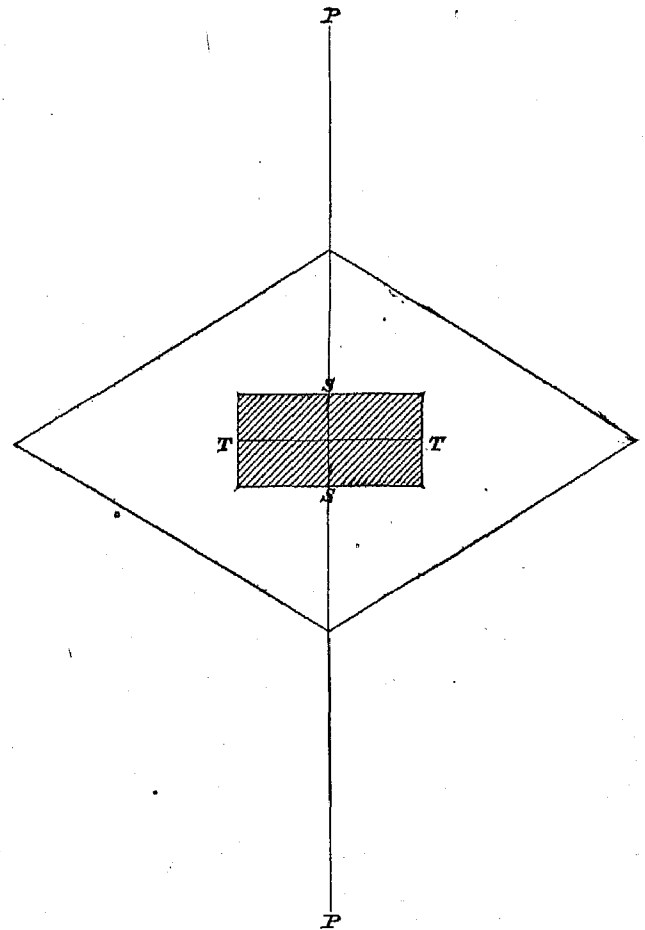


FIG. 2.

in a variety of ways. By passing through a plate of tourmaline cut parallel to the axis of the crystal the light, as previously explained, is divided into two sets of vibrations at right angles to each other, one of the sets being almost entirely absorbed, while the other is mostly transmitted as a polarized beam. Polarization is ordinarily effected by passing a beam of light into a crystal of calcite, which is cut in such a manner that one set of vibrations is allowed to pass through while another set is reflected away. A crystal so modified as to accomplish this object is called a Nicol prism, as such prisms were first made by the celebrated scientist Nicol.

Let us suppose that a beam of light is allowed to pass through a Nicol prism, and that its vibrations are all reduced to one plane, which vibrations take place parallel to the shorter diagonal of the Nicol prism, as represented in the accompanying Fig. 1; P P will then represent the plane of vibration of the light. If the aforementioned plate cut from a tourmaline crystal be now placed above this Nicol prism so that the long axis of the crystal plate shall coincide with the line P P, the crystal when looked through will be illuminated by light, the vibrations of which take place parallel to its axis, and it will appear of a color brown or blue, according to the variety of

tourmaline thus examined. If upon this same Nicol prism the plate of tourmaline be laid with its long axis perpendicular to the line P P, as shown in Fig. 2, the light passing through the Nicol prism will have its vibrations confined to a plane perpendicular to the axis of the tourmaline, and in this direction, as has been before mentioned, the tourmaline allows but little light to pass. A tourmaline crystal, therefore, placed above a Nicol prism, will appear light when placed with its axis parallel to the short diagonal of the Nicol prism, and dark when placed with this axis parallel to the long diagonal; and in general the appearance of crystals may depend more or less upon the relation of their axes to the planes of vibration of the light which passes through. This difference is expressed by the word dichroism. A great many minerals are dichroic, as is abundantly illustrated in the figures.

If the Nicol prism shall remain in the same position as before, and the tourmaline crystal shall be placed in a diagonal position, then the light which, after passing through the Nicol prism, vibrates in the plane P P meets the tourmaline crystal in a plane which coincides neither with its longer axis or the perpendicular thereto, as shown in Fig. 3; it therefore cannot pass through the crystal in the plane P P, since, as before explained, the only planes in which the light can pass through this crystal are a plane parallel or a plane perpendicular to the axis of the crystal. Meeting now the crystal in an oblique direction, the ray can only pass through it by resolving itself into two parts, according to the parallelogram of forces.

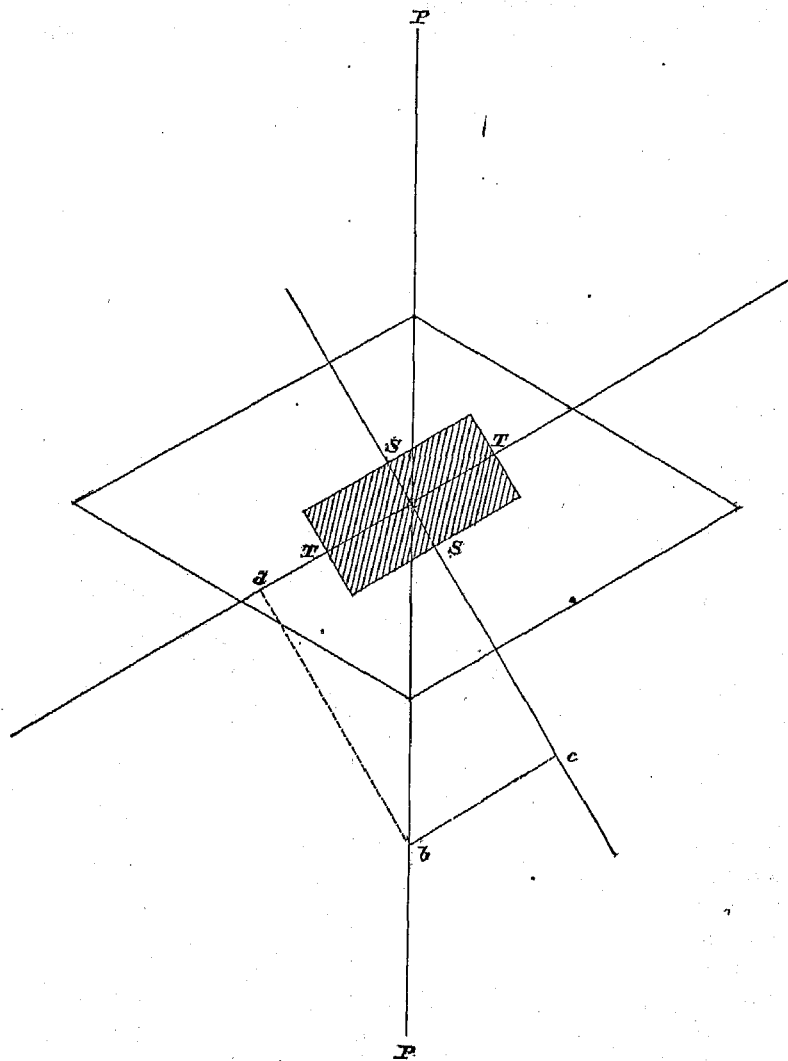


FIG. 3.

Let $a b$ represent the intensity of the vibration as it emerges from the Nicol prism; this ray will divide itself into the part $b c$, which will pass through the crystal in the plane T T and into the part $b d$, which is perpendicular to the line T T, and which, as far as possible, will pass through the crystal in this direction. The crystal in this position will be illuminated by the light which passes parallel to the two directions at right angles to each other in the crystal, and will appear as if examined by ordinary light.

The above explanation of dichroism will explain a great many of the differences in the appearances of minerals when seen in their sections under the microscope; and it also explains a number of appearances which are commonly observed without the aid of instruments. For example, when one looks through a crystal of mica in a direction perpendicular to the laminae, the color is determined by the light which vibrates in directions parallel with the laminae, and is of a certain color. If one looks at a crystal of mica in a direction parallel with the laminae the crystal is illuminated partly by light which vibrates perpendicular to the laminae, and the color is consequently different. The dichroism of minerals, thus determining a great many of their appearances, is of both economic and scientific importance.

If the light which has passed through the Nicol prism in the plane $P P$, as before explained, shall be compelled to pass through another Nicol prism exactly like the first one, but placed in a direction with its short axis perpendicular to the plane $P' P'$, the light will meet this Nicol prism in such a way that the light cannot pass it; for this Nicol prism, being like the first, reflects away all of the vibrations which enter it parallel to its longer diagonal. Through two Nicol prisms placed in this position light cannot therefore pass, and the portion of the field covered by both of them will appear dark; and if the tourmaline plate be interposed between them with its long axis parallel to the short diagonal of the lower Nicol prism, the light after passing through the lower Nicol prism will pass through the tourmaline as before explained, and will be cut off as before by the upper Nicol prism. The interposition of the tourmaline will therefore produce no effect, and it will appear black when thus placed between two Nicol prisms, as indicated in Fig. 4.

But let it be supposed that two Nicol prisms be placed together, with their shorter diagonals in the directions $P P$ and $P' P'$; that the crystal of tourmaline be placed between them in such a way that its axis does not correspond with the diagonal of either Nicol prism, as shown in Fig. 5, the light will, as before shown, be resolved into two parts in order to pass through the tourmaline in the planes $a c$ and $a d$. If we follow the course of the ray $a c$, we find that it meets the second Nicol prism in a plane which does not correspond to either its shorter or its longer diagonal; as the light must pass into the prism parallel to one or both of these diagonals, the ray $a c$ is again divided according to the parallelogram of force and enters the Nicol prism in two planes with an intensity and a direction represented by $a e$ and $a g$. The light vibrating in the plane $a g$ is in the upper Nicol prism reflected away, and only the light represented by $a e$ passes through it. If we follow the course of the ray represented by $a d$ in like manner, it is seen that it must be divided into two parts, vibrating in planes respectively parallel to the shorter and the longer diagonal of the Nicol prism, and in like manner represented in direction and intensity by the lines $a k$ and $a m$; $a k$ in the upper Nicol prism is lost by total reflection, and $a m$ passes through. We now see that by the interposition of the crystal with its long axis placed diagonally a decomposition has been brought about by means of which two rays, represented by $a e$ and $a m$, are caused to vibrate in the same plane after having passed through different experiences. The possibility of interference becomes immediately evident, for if a greater retardation has been effected by passing through the crystal in a direction parallel to the prism than in passing perpendicular to the prism, then the two parts can no longer vibrate in unison, and when they are brought back into the same plane with each other they will be sure to interfere. This interference, in fact, takes place under such circumstances, and the result is the production of most brilliant colors, the tints of which are dependent upon the nature of the substance, the thickness of the plate of the crystal interposed, and the position of the plate or section with reference to the diagonals of the Nicol prisms.

As the position with reference to the Nicol prisms brings about such modification, it is evident that the employment of polarized light will develop many peculiarities of structure and arrangement which could not otherwise be detected. In polarized light, minerals which may give no indication of their nature in ordinary light may exhibit such distinctive properties as render their determination very easy.

Those crystals through which light passes in two planes at right angles to each other, as distinguished from those substances through which the light passes without any further modification than a simple change of direction, are called double refracting crystals. These crystals show such peculiarities in their double refraction that it is possible to classify them into systems identical with those which would result from a study of their outer forms were they possessed of perfect external development.

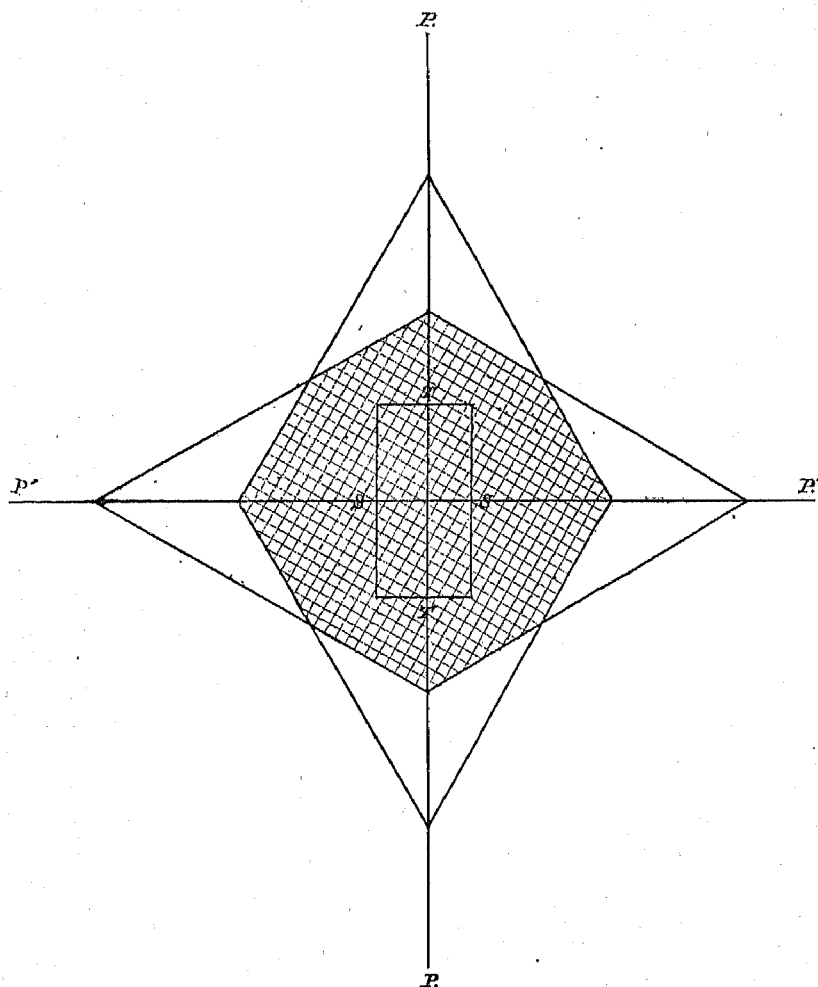


FIG. 4.

The mode of crystallization determines, therefore, the way in which light is modified by its passage through a section, and individual substances possess in addition their own peculiarities which enable them to be determined. The optical characteristics depend upon the degree of symmetry which crystals possess, and the following are some of the properties which substances of like crystalline character will exhibit: Amorphous substances, such as glass, which occurs in the volcanic rocks, and which are without any crystalline structure, will possess the property of single refraction, will not modify the light by changing the planes of its vibration, and consequently the effects of dichroism and of color with Nicol prisms will not appear, except as they may be caused by a strain or unequal pressure which may give to such a substance a temporary structure.

A crystal belonging to the isometric or regular system is symmetrically developed about the central point. In such bodies the molecular arrangement is therefore such that sections cut in any direction are alike as regards refraction, and such minerals are optically like amorphous substances, save that they may possess definite cleavage, crystalline outlines, inclusions arranged in a definite manner, or some other peculiarities which may demonstrate that they belong to the group of regular crystals. Garnet, fluor-spar, and some other substances that are found in the rocks belong to this class.

Crystals built in the form of a square or of a hexagonal prism, like tourmaline and calcite, possess, however,

a different degree of symmetry. In a section of such a prism parallel to the base, any two lines drawn through the center perpendicular to each other would intersect the crystal section in the same manner, and the two lines would be therefore crystallographically identical; there would be no cause for double refraction, and the section would therefore appear between Nicol prisms like the preceding.

If, however, a section be cut from such a prism parallel to the long axis, two lines drawn in this section perpendicular to each other will divide the section in very different manners, and these lines will bear different relations to the crystal section. A line parallel to the longer direction of the section or a line perpendicular thereto will each divide the crystal into two symmetrical halves, which, however, in the two cases are quite different. Such a section will be double refracting, and when placed between the two Nicol prisms will modify the direction of the vibrations which will take place in two planes, one parallel and one perpendicular to the crystal, and one of these sets of vibrations will be retarded more and refracted more than the other by passing through the crystal. Such a section will therefore be colored in whatever position it may occupy between the Nicol prisms, save when its long or its short axis is parallel with one of the diagonals, as shown in Figs. 4 and 5.

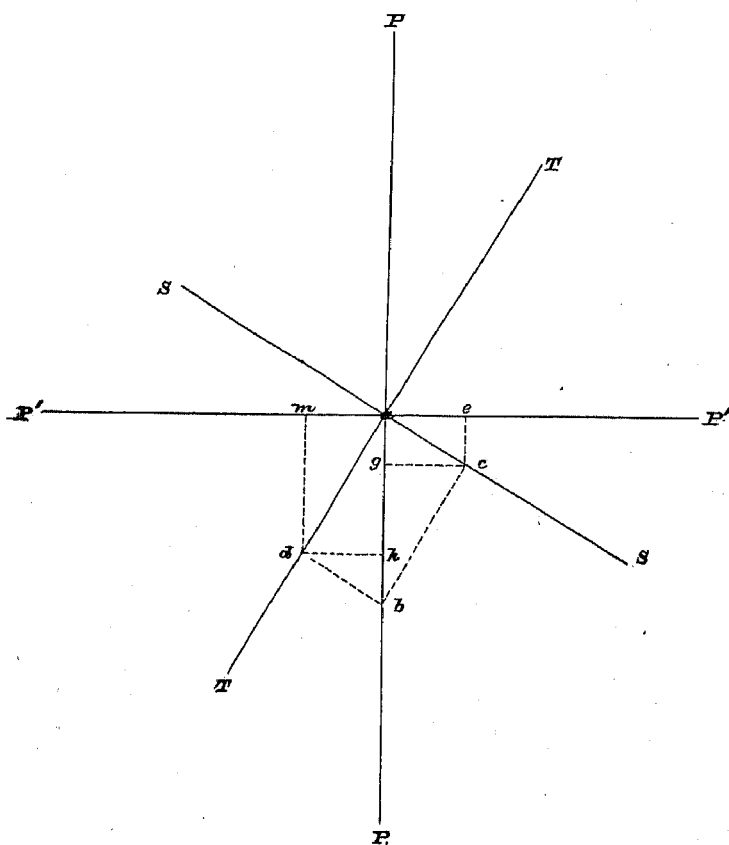


FIG. 5.

If a crystal be developed in such a way that length, breadth, and height are all different, but so that the sides of the prism are perpendicular to the base, as in the case of mica, then sections cut in any direction parallel to the sides of this prism will possess the properties which have been above described as belonging to a section cut parallel to the long direction of a square prism, for such sections will possess the same degree of symmetry and therefore the same optical properties.

If a crystal is developed in such a way that one of the faces of the prism is perpendicular to the base and the others are not, as in the case of common feldspar, then sections parallel to the base and to one side would be parallelograms resembling the long section from a square prism, and would have like optical properties. Other sections cut parallel to the oblique faces of the prism would be rhomboidal in form, and would not possess such lines of symmetry. Lines parallel to the edges of the prism would not divide the section into two parts which would be alike on the two sides of the lines, and these lines would therefore no longer determine the planes in which the light will pass through the section. No two lines perpendicular to each other in such a section can be crystallographic lines, and as the light must pass through such a section, like all others, in two planes which are at right angles, these directions must be independent of the crystal edges, and will depend on the individual mineral rather than on a general system of crystallization. One single example will illustrate all these principles.

Let Fig. 6 represent a crystal of feldspar which belongs to the monoclinic system, last described, and which, if thus simply crystallized, would have the planes on the two sides of the lines ac and ad at right angles to each other, while the planes on the sides of ab would form an obtuse angle. Sections cut parallel to the base and the front face of this prism would then be right-angled parallelograms, and lines through the centers of these faces and parallel to the sides would be at right angles to each other, and would divide them into equal and symmetrical halves. These represent, therefore, the planes in which the light must vibrate in passing through the crystal, and are the planes which must coincide with the diagonals of the Nicol prisms, or interference and colors will be produced.

The plane on the side, however, is not a parallelogram, and lines parallel to its sides are not perpendicular to each other. The light, therefore, finds two directions, for example, eg and hi , which are at right angles to each other, in which its vibrations take place. These directions, which make a certain angle with the lines parallel to the edges ac and ad , have the same position in all crystals of like substances, and occupy different positions in crystals that belong to this system, but are of different substances. These lines are the lines which correspond with the lines parallel to the edges of the crystal in the sections parallel to the other faces, and the angle made by the optical and the crystallographic lines can be measured, and its determination may identify the species of the substance.

Only one case remains to consider. If a prism is so developed that it possesses no right angles, then sections parallel to any face are like the face on the side of the prism in our example, and therefore all its sections will have the properties attributed to sections parallel to that face, and no sections will be found in which the planes of vibration of the light are parallel to the edges of the prism.

A great many more optical effects can be produced by causing other modifications in the light; for example, by making it convergent by means of lenses before it passes into the section. Effects thus obtained elucidate those that have been described, which are seen in simple parallel light. In this work only the optical features that have been described are referred to.

When these principles are applied to the microscopic examination of thin sections we are able to identify all of the constituents which the rock contains by means of the differences which the minerals exhibit either in ordinary or in polarized light. The determination is simplified by the circumstance that the number of minerals which take part in the composition of common building stones is not large.

When a section is placed upon the stage of the microscope most of the ingredient minerals are transparent, and the number which do not become transparent under this treatment is so small that there is no great difficulty in discriminating between them. To determine the opaque ingredients the light is cut off from beneath the stage of the microscope, when the color of these opaque minerals, as they appear by a reflected light, is seen; magnetite is bluish-black, pyrites yellow, etc.

Those minerals which are more or less transparent in the section exhibit the colors which they possess by transmitted light; but, in accordance with the principles already explained, sections of the same substance may be differently colored according to the directions in which their crystals are intersected. A considerable number of the minerals may be identified by their colors and appearances, and others may be identified by known peculiarities of fracture, cleavage, and decomposition.

If a Nicol prism is inserted beneath the stage of the microscope it will not essentially modify the appearance of most of the minerals, but as it will reduce the vibrations of the light which illumines the section to a plane, the phenomena of dichroism will become apparent, and by means of these phenomena some of the ingredients will be identified.

If a second Nicol prism is placed above the first, so that the section lies between the two, then all the phenomena of polarized light become evident; and if these Nicol prisms are placed in such a position that their shorter diagonals are crossed at right angles, and that the direction of these shorter diagonals is accurately known, then the relationship between the diagonals of the Nicol prisms and the planes in which the light vibrates when passing through the crystal section can be determined, and little doubt concerning the composition of any mineral in ordinary rocks will remain after the application of all these methods.

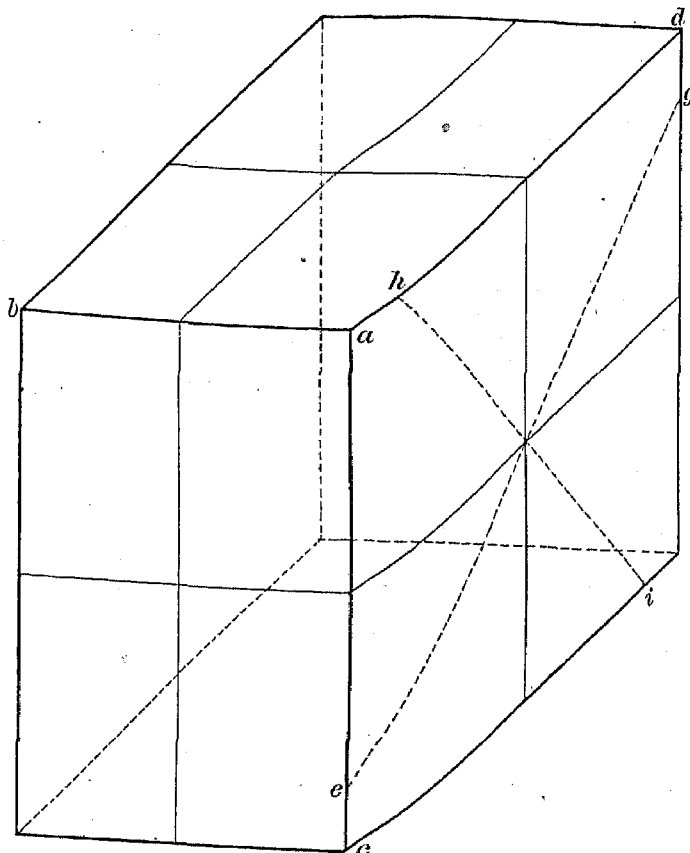


FIG. 6.

CLASSIFICATION.

The nomenclature in general use for materials of construction is very simple. It consists of a few popular names with no defined significations. These names are derived at times from certain characteristic appearances, and sometimes from the uses to which stone is applied. They answer most of the purposes of constructors; but, when examined more critically, stones which pass under the same name are frequently found to be so different as to necessitate their wide separation from one another in classification.

Some so-called granites in the United States do not contain one of the minerals which compose certain other well-known granites, and possess nothing in common with them except their granular structure. Such differences in composition essentially modify the economic properties of the stone, and there is for this reason a positive advantage in a more extended nomenclature. Closer discrimination in this direction will also necessitate a more critical consideration of the stones from different sections of the country. We hear very frequently of such things as Ohio sandstone, Maine granite, etc., which are terms that include stones that are incapable of being grouped; and the cases are not rare in which, by reason of such generalizations, the good or bad reputation of certain stones has unjustly passed over to its neighbors.

Individualities of structure and composition of the greatest scientific interest are usually identical with the features most important from a practical standpoint, and therefore for our use the scientific nomenclature of rocks can scarcely be improved. This nomenclature differs but slightly from that in common use, and this is due to the circumstance that the old popular names given by miners and quarrymen to ores and stones have always been used in mineralogical and geological studies. The great variety of practical applications which these studies find in the arts has rendered difficult and impracticable the introduction of such a system of generic and specific names as characterizes the more modern sciences, which are not so directly applied in common life; but it is noticeable that many old names, like trap, greenstone, lava, etc., which still are used in the popular nomenclature, have long since been banished from scientific works as meaningless.

The earth is covered with hard rocks and the loose products of their disintegration. If the hard rocks have resulted from a cementation and consolidation of what once was loose material, they maintain the stratified character of the original bed. When heat, moisture, or any other agencies have rendered them very compact and resistant, they still retain some traces of their original stratified character; and whenever it can be shown that a given rock was once composed of those loose products of the disintegration of older rocks, it is called stratified. The different members of the stratified group of rocks are often very unlike one another. They are sometimes composed of merely cemented masses of sand or pebbles, and their origin is very plainly seen; at other times the original constituents and the original structures are both nearly obliterated by subsequent processes of modification. Their stratification is in some cases very plain, and modifies the processes which are used in quarrying and in dressing the stones, as well as the uses to which they are applied. In other cases the stratification is with difficulty detected, and shows itself only when large masses of the stone are seen, or in the greater ease with which the stones are worked in given directions.

The process of cooling from a molten state, through which the earth has passed, has necessitated a constant change of volume and consequent strain upon its crust. Thus in every age of the world's history clefts have been formed through which materials have issued in molten condition from the interior of the earth, and have been poured forth in greater or less quantity upon its surface. Such materials cooling from a molten condition do not possess stratification, but are massive and crystalline. The modern volcanic rocks belong to this class; some of these are light, porous rocks, which are easily worked and are much used in countries where they abound. They are not employed to any extent in the United States, because there is little construction in those regions where they are abundant. The older granitic rocks of this class are hard, compact, and durable. Mechanical forces which have acted upon their surfaces for long ages have worn down and removed any soft and porous material which might have existed. They are quarried with more difficulty, and consequently are not so extensively employed as the sandstones and the limestones of the stratified group, but they possess such properties as make them favorite materials of construction. In general, the sedimentary and the volcanic rocks possess structures that render them more easily cut and worked, while the ancient massive rocks are more hard and durable. The ready accessibility of the granitic rocks in the most thickly settled portions of America has caused them to be more extensively used among us than in any other country in proportion to the amount of stone construction.

These considerations divide rocks into two principal groups, each of which may be subdivided. The further subdivision depends upon the mineralogical composition of the individual stones, as is indicated in the following classification.

If this classification is rigidly adhered to, numbers of rocks which are related by those physical properties that determine the uses to which they are applied are quite widely separated from one another. Gneiss, for example, is so much like granite that it is often used in the same way for the same purposes. The rocks which are related in composition are conveniently grouped together as being the material of one and the same industry, even though their mode of origin is recognized as different.

The following tabulation forms the basis for comparison of the industries considered in this work, and for convenience a name is given to each group, which is either that of its predominant member or that by which the stones that compose it are commonly known:

- | | |
|-----------------------------------|---------------------------------------|
| 1. Granite. | Conglomerates. |
| Syenite. | Breccias. |
| Gneiss. | 3. Carbonates (limestones). |
| Crystalline schists. | Common limestones and dolomites. |
| Diabase. | Crystalline limestones and dolomites. |
| Diorite. | Shell limestones. |
| 2. Fragmental rocks (sandstones). | Calcareous tufa. |
| Siliceous sandstones. | 4. Serpentine. |
| Feldspathic sandstones. | 5. Slate. |

In this report, then, the rocks at present used for purposes of construction in the United States are for convenience divided into the following classes:

1. Crystalline siliceous rocks.
2. Sandstones.
3. Marble and limestones.
4. Serpentine.
5. Slates.

Rocks popularly known as marble and limestone are classed together, owing to the difficulty of drawing a definite line between the two; all distinctively calcareous rocks are included in this table.

The group headed "Sandstone" comprehends all the siliceous rocks not included in the tables of the crystalline siliceous rocks and serpentine. Materials commonly known as sandstone, freestone, flag-stone, some of the so-called "blue-stones", quartzite, and all the conglomerates, except the calcareous conglomerates, come under this heading.

In the class of crystalline siliceous rocks are placed those popularly known as granite, syenite, gneiss, mica-schist, trap, basalt, porphyry, and volcanic rocks.

Serpentine was quarried during the census year, to a sufficient amount to admit of tabulation, only in Pennsylvania, and even here the product was small as compared with that of previous years. The greater part of the slate product tabulated has been used for roofing, though a portion of it was employed for sidewalk paving, tiling, and other purposes of construction.

States and territories wherein any one of the classes of rocks above described are not quarried for purposes of construction are, of course, omitted in the tables devoted to that particular class, though many states and territories are rich in the undeveloped material.

DECOMPOSITION OF STONES.

There are many more factors which determine the value of stones for purposes of construction than are often considered in the elementary treatises upon this subject, and the rules laid down are often determined by the local circumstances. A more extensive study of building stones frequently vitiates the rules which apply in limited areas. It is, for example, stated that, in order to determine whether a stone will withstand the action of the weather, one should visit the quarry and observe whether the ledges that have been exposed to the weather are deeply corroded, or whether these old surfaces are still fresh. This is not a fair criterion, because the applicability of such a test is modified by geological phenomena. North of the glacial limit all the products of decomposition have been planed away and deposited as drift formation over the length and breadth of the land. The rocks are therefore in general quite fresh in appearance, and possess but a slight depth of cap or worthless rock. The same classes of rock, however, in the south are covered with the rotten products resulting from long ages of atmospheric action. They may be rotten to great depths, and the removal of the worthless rock is often difficult. This is due to the circumstance that no agencies have here operated to scrape off and remove the loose material from their surfaces in recent geological time.

There are other peculiarities of decomposition regarding which too absolute rules have been laid down. Pyrites is considered to be the enemy of the quarryman and constructor, as it decomposes with ease and stains and discolors the rock. But here, too, there are features which very seriously modify the effect of this decomposing substance. Pyrites, in sharp, well-defined crystals, sometimes decomposes with great difficulty. If a crystal or grain of pyrites is embodied in soft, porous, light-colored sandstones, like those which come from Ohio, its presence will with certainty soon demonstrate itself by the black spot which will form about it in the porous stone, and which will permanently disfigure and mar its beauty. If the same grain of pyrites is situated in a very hard, compact, non-absorbent stone, the constituent minerals of which are not rifted or cracked, this grain of pyrites may decompose and the products be washed away, leaving the stone untarnished.

We believe that the microscopic study of these stones is, even in such simple cases as this, necessary for a correct determination as regards the influence of decomposing agents upon the stone.

Again, some of the constituent elements of rocks are so frequently found in a decomposed condition that they are considered to be deleterious, when present in large quantity, on account of their well-known tendency to decompose. For example, olivine indicates a very marked tendency to decompose, as indicated by the vast accumulations of serpentine which are so frequently found to be a result of its decomposition; but the circumstances which in past time have brought about this decomposition may have been very different from those which are at present active, and the prejudice against olivine in a rock is not supported by any observations which indicate that it will decompose under the present influences. We wish to bring prominently forward that we consider that a decision as to the probable action of the agents producing decomposition in rocks should be largely dependent upon careful microscopic examination of the structure of the rock. Our experience has demonstrated that a rock of a given character, as regards ultimate composition and mineral constituents, may be easily affected by the weather if its constituent minerals, as indicated by their microscopic structure, are so fractured that they are laid open to atmospheric agencies through rifts, no matter how small, while the same stone, with the same constituents, may be eminently resistible to decomposing agencies if its constituent minerals are sound, whole, and impermeable, as indicated by the microscopic structure.

In the old world, where immense cathedrals, planned long ago, have been in the process of construction for hundreds of years, it has not been uncommon to see portions of the building fall into decay before the structure was finished, and the process of restoration often consumes large sums of money while the process of construction is yet going on. It thus very frequently happens that a variety of stones is used in the construction of the same building, because in this process of construction experience is gained indicating inapplicability of the stones used for durable structures. In this case it is experience alone which finally dictates the most suitable material; and even to this day, here in America, there is no other criterion to apply to a building stone save the test of experience; and the result is that buildings can be pointed to which, like those old, immense structures before referred to, are already crumbling while yet in the process of construction.

PRESERVATION OF STONES.

Disintegration of stone and the method by which this can be arrested has furnished a topic for considerable study. The methods which have been applied with most success are to bathe the stones in successive solutions, the chemical actions between which bring about the formation of insoluble silicates in the pores of the stone. For example: If a stone front is first washed with an alkaline fluid to remove dirt, and this subsequently followed by a bath of silicate of soda or potash and allowed partially to dry, and then bathed again; and if the surface is then bathed in a solution of chloride of lime, chlorate of sodium or of potassium, according to what is used, an insoluble lime silicate is formed. The soluble salt is then washed away and the insoluble silicate forms a durable cement and checks the disintegration. If lime water is substituted for chlorate of lime there is no soluble chlorate to wash away.

INFLUENCE OF CLIMATE.

In addition to the consideration of the humidity of the atmosphere, the influence of the purity of the atmosphere is also important in deciding on a building material. For example, in the smoke of Pittsburgh it would make very little difference what the material employed for construction might be, so far as appearances are concerned, since it would soon assume the gray color peculiar to all the buildings of the city; but the capacity of a stone to resist acid vapors would become very important, since the only point necessary to be considered in selecting a stone would be as to whether ornamental structures are defaced and disintegrated by the vapor fumes peculiar to this atmosphere.

STRENGTH OF MATERIALS.

In practice it is not common to place stones where they are obliged to bear more than one-sixth or one-tenth of the weight which their crushing strengths, as determined by experiments, indicate that they are able to bear. Beside this, there are many considerations which demonstrate that reliance upon experimental data is unsafe. A stone that will crush under a given pressure to-day may, if exposed to the weather, crush under a very much smaller or very much larger weight after the passage of years, according to the action of the weather upon it. Stones, when they crush, usually break in certain lines of weakness, which lines may be arbitrarily situated in the stone and difficult to detect, or may be definitely situated and dependent upon structure. As stones from different parts of the same quarry, and even from different places in the same layer, frequently vary greatly in strength, it is quite important to develop methods by which the strength of stones and their variability in this respect can be more easily detected than by the laborious experimental tests upon small cubes. Results of studies made upon the structure and composition of those stones which have been very accurately tested as to their strength are valuable contributions in this direction.

CHAPTER II.—MICROSCOPIC STRUCTURE.

BY G. P. MERRILL.

It is not the intention in this chapter to present a purely scientific treatise on microscopic lithology, but rather to give a short description such as together with the plates will enable any one with but a slight knowledge of the subject to appreciate the variations in structure and mineral composition of some of the more common kinds of building stones. What may be considered as typical specimens of the various kinds of rock quarried have been selected, and from the thin sections, prepared as already described, enlarged photographs have been made from which the plates have been reproduced. They therefore show the exact structure as seen under the microscope, excepting, of course, in the matter of color. In preparing the text the manuscript notes left by Dr. Hawes have been utilized so far as possible.

THE CRYSTALLINE SILICEOUS ROCKS.

Rocks that are commercially designated as granites are composed in some cases of minerals which are entirely absent in other rocks that are also designated as granites. For example, some of the so-called black granites are diabases or diorites. But the circumstance that the minerals, although different, are all very nearly of the same hardness; that the rocks therefore offer the same difficulties in cutting, in dressing, and in polishing, and that the similarities of their appearance render them applicable to like purposes, unite these rocks into a well-defined group. In it are included the various granites, syenites, trap-rocks, gneisses, and crystalline schists.

The structural differences that exist among the rocks of this class, although indicating very different modes of origin, are fully recognized in grouping these rocks thus together.

The nomenclature for these rocks in use among quarrymen shows that they are all related as economic products; for example, the gneisses are frequently called "bastard" granites or "striped" granites, as are also frequently the mica-schists. The trap-rocks, where they are quarried, are very commonly called "black" granites or "gray" granites, and as a rule no distinction whatever is made between the granites and syenites. Therefore, in a tabulation which shall indicate the extent to which the hard crystalline rocks are quarried, and shall give the data for comparing one well-defined industry with the others, these rocks are naturally associated together.

Although, as shown, these rocks do possess common characters that unite them into a well-defined group, they possess differences which allow the group to be subdivided both according to the appearances and uses of the stones. The granites and gneisses, for example, possess the common characters already referred to, but the resemblance extends no further. It is therefore a positive disadvantage to the industry to classify them, as is so frequently done, under a common name. Therefore, in the tabulation the common name by which the stones are sold will be given, accompanied by the scientific designation.

These rocks are found chiefly among the older formations and in regions where there have been such disturbances as have cleft the crust of the earth and given egress to the fused matters which underlie it. The crystallization of these molten materials which have thus been erupted has given rise to many of the rocks which, on account of their massive homogeneous structure, are most prized. Quarries of these rocks occur in all the Atlantic states, the Lake Superior states, and in the mountainous regions of the far west. Thus the great interior basin of the continent is left without rocks of this class, if we except some isolated areas in Missouri, Arkansas, and Texas.

It is not, however, to be inferred that all of the rocks of this group are as old as the rocks which characterize these regions. The gneisses and the crystalline schists are very old rocks, belonging mostly to the Archæan period. The other members of the group are eruptive rocks which have at some period in the earth's history been molten, and have been forced through clefts in these older rocks. There is, therefore, no method of determining their exact age in all cases, since the time of their eruption can only be determined as being later than the time when the rocks which they intersect were accumulated. It is, however, known that a great many of them are very old, and that the time of their eruption was probably identical with the elevation of the mountains and the disturbances which would have naturally resulted in producing the clefts through which they were erupted; and it is also known that some of them are quite modern in age, since they intersect sandstones which were accumulated in later periods of the earth's history.

GRANITE.

The essential components of the true granites are quartz and potash feldspar. Although the essential minerals are but two in number, the rocks are rendered complex by the presence of numerous accessories which essentially modify the appearances of the rocks and those properties which render them of importance as building stones. These additional minerals are either present in such amount as to be conspicuous and to exercise an influence upon the appearance and structure of the rock, when they are called characterizing accessories, or they are present in such small amount as to be invisible to the naked eye, when they are called microscopic accessories. If all the minerals which by careful examination have been found in granites should be considered as constituents of the rock, then the latter would appear as very complex. At least two-thirds of all the known elements exist in granitic rocks, and the number of minerals that are liable to be present in special cases is very large.

The following list does not include all of those minerals which have been identified in this rock, for many have been found under circumstances which are so isolated that their occurrence is entirely exceptional. All of the minerals in this list are liable to be found at any time, and may therefore be considered as common constituents of the rock, although the presence of them all together is not to be expected, and some of them may be present in such minute amount as to be of no practical importance. Any one of them, save the two essential constituents mentioned above, may be absent from an individual specimen, or from a granite from a given locality; and any one may be present in the specimens from a given locality in such amount as to give a character to the rock. Thus almost any one of those minerals which are given as microscopic accessories may assume the character of a characterizing accessory; this is especially true of the iron oxides, which sometimes are present in such amounts as to become characteristic:

Essential:

Quartz.
Feldspar.
Orthoclase.
Microcline.
Albite.
Oligoclase.
Labradorite.

Microscopic accessories:

Sphene.
Zircon.
Garnet.
Danalite.
Rutile.
Apatite.
Pyrite.
Pyrrhotite.
Magnetite.
Hematite.
Titanic iron.

Characterizing accessories:

Mica.
Muscovite.
Biotite.
Phlogopite.
Lepidolite.
Hornblende.
Pyroxene.
Epidote.
Chlorite.
Tourmaline.
Acmite.

Decomposition products:

Chlorite.
Epidote.
Uralite.
Kaolin.
Iron oxides.
Calcite.
Muscovite.

Inclusions in cavities:

Water.
Carbon dioxide.
Sodium chloride (salt).
Potassium chloride.

The feldspar, which is so easily recognized by its cleavage surfaces in all of the granites, is by far more complex in composition than has usually been supposed. It is exceptional to find a granite which contains but one kind of feldspar, and not merely are two or three species usually present, but the structure and condition of their crystals are far from simple. The potash feldspar sometimes exists in the form of orthoclase and sometimes in the form of microcline. Microcline is a feldspar of the same composition as orthoclase, but differs from it in crystalline form by belonging to the triclinic system, which possesses no right angle. The orthoclase is very commonly seen in crystalline grains, in each of which one-half bears the relation to the other half of one crystal revolved 180° about an axis in another. Such are called twin crystals. They render themselves conspicuous to the eye in some granites by the different positions in which one receives the bright reflections from the two sides. The microcline is divided

into such a multitude of twinned parts that they are only recognized by a microscopic examination, and in addition two different systems of twinning combine to make the structure more complex. Therefore, in the thin sections, while the orthoclase at the most is divided into two parts by a straight line, the microcline as seen in polarized light possesses a reticulated structure, which is due to the interweaving of the multitude of laminae that stand in the relation to one another of twin crystals. This structure will be noticed in the plates.

The discovery of this species of feldspar has been one of the developments of microscopic mineralogy, and examination has proved microcline to be one of the prominent constituents of granites.

The albite, oligoclase, and labradorite are identified in thin sections by the circumstance that they possess also a complex twinned structure; but one system of twinning preponderates, so that they possess a banded structure which evinces itself in the fine parallel striation that is frequently seen on its bright cleavage surfaces with the unaided eye, and in thin sections the same is much more plainly shown by the banded structure that its sections possess in polarized light when the crystals are cut in some plane that is not parallel with the plane of the lamination. The optical properties of the individual species render it possible to still further identify them; or they may be analyzed when it is possible to separate them from the rock.

The different kinds of feldspar that exist in these granites are sometimes separated from one another in distinct grains, and sometimes are interlaminated with one another, forming complex grains. For example, orthoclase and albite are frequently combined in the same crystal or grain.

All of these circumstances of composition and structure are important, for the appearances of granites depend largely upon the feldspathic ingredient. The different species are often quite differently colored, and thus at times a beautiful mottled appearance is imparted to the stone; if, for example, the orthoclase feldspar is red and the albite or oligoclase is white, the effect of this mixture of colors is strikingly manifest. If both kinds of feldspar are white, one may be opaque and the other transparent, or one may be opalescent and the other dull. In general, many of the most striking characteristics and a large proportion of the immense diversity in granitic rocks are due to this complexity in the feldspathic constituent, and its consideration is one of the most important elements of their study.

The feldspar has also an influence upon the cutting of the stone and its shade of color. The so-called hard granites consist of quartz with a compact, transparent, nearly glassy feldspar, which is quite difficult to cut, and which allows the light to enter it and be absorbed, thus imparting to the stone a dark color, as in the case of the Quincy granite. The cause of the hardness of these rocks is not entirely due to the quartz, as is often supposed. Quartz is always brittle, and is not very variable under tools. The hardness of hard granites is due to the condition of their feldspathic constituent, which is variable. The soft granites, however, consist of the same constituents, but the feldspar is porous and is thereby rendered soft and less resistant to the tools. The light is reflected under these circumstances from the surface and the rock is rendered white. It bears the same relation to the feldspar of the hard granites as does the foam of the sea to the water, but of course in a less marked manner. The Concord granite may be mentioned as an example.

The structure of the feldspar modifies the resistibility of the stone to decay, the quality of the polish which may be imparted, and the ease or difficulty with which the stone may be discolored or stained.

The quartz is much more simple in structure, and is subject to many variations in form and appearance, but to none in composition.

Although belonging to what we call the infusible substances, it is evident that in the solidification of the granitic rocks such agencies were active as rendered this substance more easily fusible than the other ingredients, and it was therefore the last element to take final form in the solidification. This is shown by the way in which it occupies the interspaces which were left after the other minerals had crystallized, and it therefore, to a certain extent, acts as a kind of cementing material to the other ingredients. Some granites contain large, imperfect quartz crystals, which must have been one of the first products of the solidification, but in nearly all granites the last substance to solidify is the quartz.

The microscope indicates that the quartz almost always contains pores which are partially filled with fluids. The number and size of these pores are of considerable importance, as they tend to explode when heated, and this aids to disintegrate the rock at a high temperature. It is important to note, however, that the various minerals which compose granites possess different expansibilities, and this is a cause of the well-known tendency of granites to disintegrate in the fire. Granite usually contains about eight-tenths of one per cent. of water, and is capable of absorbing a few tenths more. The water permanently present is largely contained in these pores when the rocks are fresh, and the capacity for further absorption is due to the rifts and empty pores that are largely confined to the feldspar.

At times quartz and feldspar constitute almost the whole of the rock, and at other times the accessories become very prominent. These accessories vary with the locality, and give the characteristics to the various kinds.

Mica is the most common of the accessory ingredients, and its presence constitutes what is called mica granite. If the mica is the white muscovite, the granite may be very light in color and may be almost white, as in the case of the Hallowell granite, or the granite from Barre, Vermont. If the mica is exclusively the black variety of

biotite, the granite will be dark in proportion as this mineral is present. If both species are present, as is frequently the case, the granite will be speckled with alternating black and white shining spots, as in the case of the Concord granite.

The amount of the mica present is economically important. It does not polish as easily as do quartz and feldspar, owing to its softness, and the presence of a large amount therefore renders the rock difficult to polish. When polished it does not retain its luster so long as do the other minerals, and its surfaces become dulled by exposure. Its presence in large amount is therefore deleterious to stones which are intended for exterior use as polished stones. The condition in which it exists is also important in this respect. A large amount of mica scattered in very fine crystals through the rock influences its value as a polished stone less than does the presence of large and thick crystals of mica scattered through the rock in smaller number. The method of arrangement of the mica is very important; if scattered at hap-hazard, and lying in all directions among the quartz and feldspar crystals, the rock will work nearly as easily in one direction as in another. If it is distributed through the rock in such a manner that its laminae are arranged in one definite plane, it imparts a stratified appearance to the rock, and when this stratified appearance becomes marked, the stone is called gneiss. One or two causes may give rise to this structure, but so far as it exists in granites it is easily explained by the circumstance that slight motions in a given direction in a plastic mass will cause all of the flat and long constituents to arrange themselves in a definite plane. If, for example, some mica scales or any other thin flat scales are mixed in clay so that they lie scattered through it in all directions, and if this clay is pressed so that it is flattened out a little, a section through the clay will show that the scales have arranged themselves in a definite plane, an effect produced by the motion of the plastic mass induced by pressure.

As granite is supposed to have cooled from a condition of fusion, the circumstances must plainly have existed under which this laminated structure could have been produced, for the mica was crystallized before the rock was entirely solid, as is evident from an examination of its microscopic structure, which shows that the mica invariably crystallized before the quartz had taken form. The effects of the parallel arrangement of minerals in granites are often evident, even when this arrangement is invisible to the unaided eye. Apparently massive granites cleave more readily in one direction than in another, and this plane of more easy cleavage is always detected by quarrymen with experience.

If hornblende is the characterizing accessory, the granites are usually without any evident stratification, as this mineral exists in the granites in granular form. Hornblende is subject to as wide variations of composition as is mica, but its white and very light colored varieties do not frequently appear in the granitic rocks. Its green varieties occur and give a characteristic shade of this color to the stone, as is illustrated, for instance, in the granite of which the new Mormon temple is built. It cleaves parallel to two planes which make an angle of 124° with each other, and is thus distinguished from mica, which invariably has but one cleavage. It is easier to polish than mica, and its presence is favorable on this account. The hornblende granites are to be classed among the best.

Pyroxene as a characterizing accessory in granites is more abundant than has usually been supposed. Indeed all rocks which contain pyroxene abundantly have usually been confounded with the hornblende granites. The distinction between pyroxene and hornblende is important from an economic standpoint, as hornblende possesses a much better cleavage than pyroxene, while the pyroxene is much more brittle than hornblende, and cracks out with greater ease in working. The cracking out of little pieces from the black ingredient of the Quincy granites has been frequently noticed, and is due to the circumstance that this granite is not the hornblende granite that it has been usually supposed to be. Hornblende is very tough, but the Quincy granite contains a peculiar variety of pyroxene, which is so brittle that it is difficult to make a large surface on a Quincy granite which does not show some little pits, due to the breaking out of a portion of the black grains of pyroxene.

Although pyroxene and hornblende may be identical in composition, they are frequently associated together in the same rock, a circumstance which is very evident in thin sections, but not in the massive stones. The rocks which contain hornblende also frequently contain mica, but it is noticeable that under such circumstances the mica is always of the dark-colored variety, and an example of a granite which contains both hornblende and muscovite is not known.

Epidote is quite characteristic when present in the granite, giving to it its deep green color. Its crystals are always green so far as observed in granite, and the polishing of the stone develops the brightness of this color. It is sometimes an apparently original constituent of the rock, and at other times a decomposition product.

The Dedham, Massachusetts, granite is one of the most marked examples of an epidotic stone. It is also frequently present in all the varieties of granite previously mentioned, and more or less modifies their appearances.

The tourmaline granite usually occurs in veins of inconsiderable size. Such granites are associated with those that are extensively worked, and in themselves are often beautiful, but they do not exist in accumulations of such size as to warrant the opening of quarries to work them exclusively. The tourmaline granites must, therefore, be considered as accessory products that exist in connection with the quarried stones, but which are not extracted for economic purposes.—G. W. H. (a)

a The chapter to this point is from Dr. Hawes' notes.

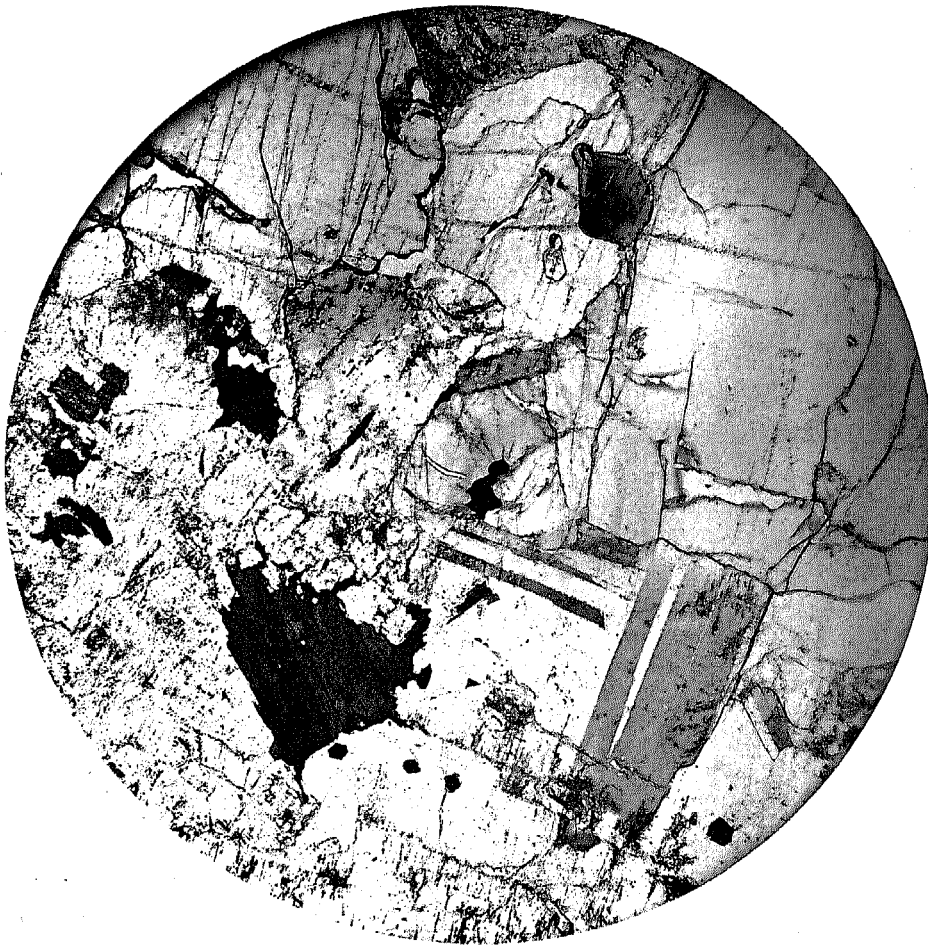
PLATE I.



Muscovite Granite,

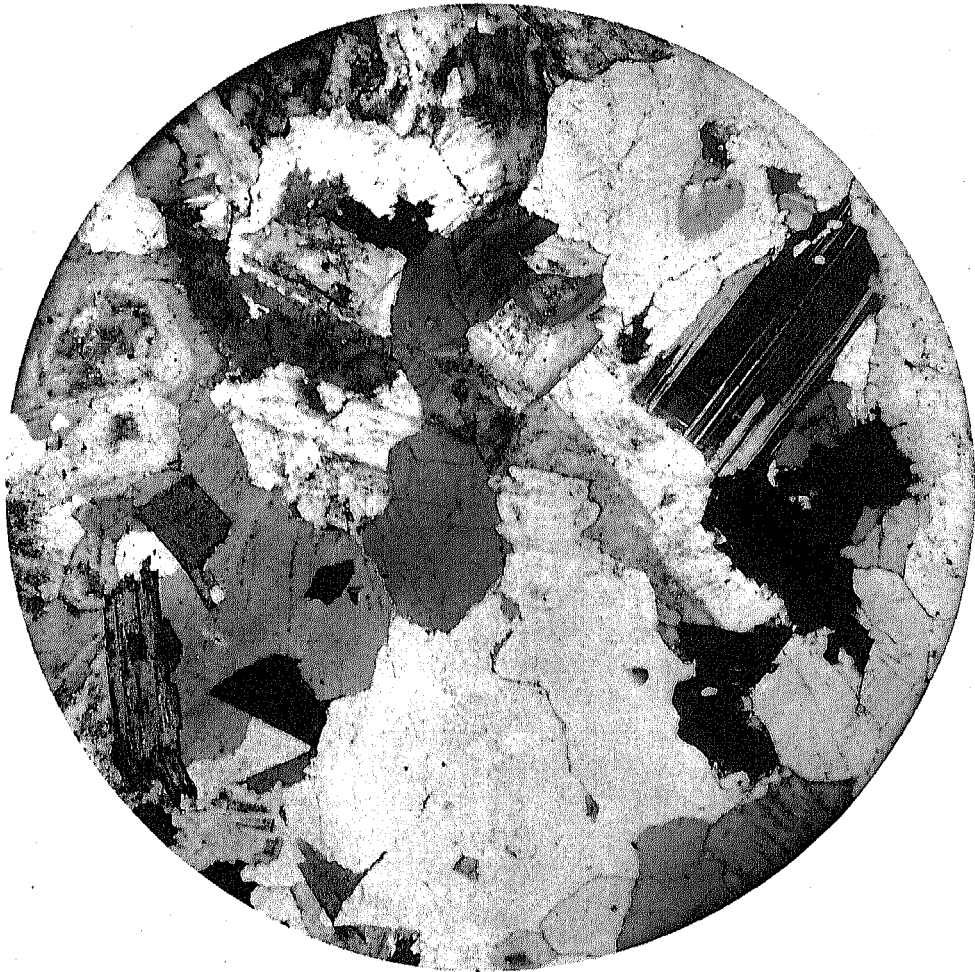
Barre, Vt.

PLATE II.



Biotite Granite,
Dix Island, Me.

PLATE III.



Biotite Granite,

Sullivan, Me.

The granites at present quarried throughout the United States may be classified as follows:

Muscovite granite.

Biotite granite.

Muscovite-biotite granite.

Hornblende granite.

Hornblende-biotite granite.

Epidote granite.

Granitell, or granite without any accessory.

Although it is possible to classify all the granites under these heads, the lines of distinction between them are by no means sharply drawn, but the different varieties merge into each other by continual gradations. For instance, nearly all the muscovite granites contain a little biotite, and *vice versa*; also, nearly all the hornblende granites, as those of cape Ann and other localities, contain some mica, although not in all cases enough to be visible without the aid of the microscope. In these cases the dividing line must necessarily be drawn somewhat arbitrarily, and it is the prevailing accessory which has given the specific name to the rock; or when two are present in such abundance as to be both evident to the naked eye, then the two descriptive names are employed, as in the case of the muscovite-biotite granite of Concord, New Hampshire, which contains both micas in nearly equal proportions.

MUSCOVITE GRANITE.

Since muscovite itself is very nearly colorless, the granites bearing this mica as their chief accessory are very light in color, being in fact the lightest of all our granitic rocks. Pure muscovite granites are not at present extensively quarried. That found at Barre, Vermont (*see* Plate I), is a coarse, light gray rock of almost marble whiteness, a polished surface of which presents a somewhat mottled appearance due to the presence of quartz and mica. The prevailing constituents are quartz, orthoclase, plagioclase, and white mica or muscovite. When examined in thin sections under the microscope the interstices between the larger crystalline grains are found to be filled with very many smaller grains of quartz and feldspar, together with shreds of mica and numerous accessories, giving rise to the structure known to lithologists as "drusy".

The mica as seen in ordinary light is quite colorless, but between crossed Nicol prisms it gives a most beautiful iridescence. It occurs usually in ragged shreds, but rarely in small forms with definite crystalline outline. A very little biotite is also present. The feldspars are the predominating minerals and occur in more or less perfect crystals, while the quartz grains fill the interspaces. The chief accessory mineral in this rock is epidote, which occurs in small irregular grains without definite crystalline outlines and is traversed by numerous fractures. In the thin sections it is of a very faint greenish color. Some apatite is also present in the form of small, colorless, six-sided crystals, which are never large enough to be visible to the naked eye.

A fine gray muscovite granite of a slightly darker shade, though much more even in texture, is quarried near Atlanta, Georgia. This rock is richer in both quartz and mica than its representative from Vermont, but contains less epidote. A large part of the feldspar of this rock is microcline, as is shown by its peculiar reticulated structure when viewed in polarized light.

BIOTITE GRANITE.

This constitutes the most widespread group of our granitic rocks, and presents also the most diversified color and structural peculiarities. A large proportion of all the granites at present quarried in the United States is referable to this group. In color they vary from light to dark gray and almost black, according to the amount of mica they contain and the color of the feldspar; the red granites, many of which belong here, owe their color to the flesh-red orthoclase, which is the prevailing ingredient. As a general thing these granites are much tougher and harder than those of the preceding group, and, if we except the porphyritic varieties, possess a more even texture, lacking the drusy structure characteristic of muscovite-bearing rocks. The texture, however, varies almost indefinitely, and it is obviously impossible to select rocks from any one locality as typical for the group. Perhaps the more common varieties are those represented by the granites from Dix island, Maine, Westerly, Rhode Island, and Richmond, Virginia.

The essential constituents of biotite granite are quartz, orthoclase, and biotite, but a plagioclase feldspar is almost invariably present, together with some magnetite and apatite. The usual accessories are microcline, hornblende, muscovite, apatite, epidote, sphene, and zircon. It is stated by Rosenbusch (*a*) that the biotite granites, as a class, usually contain less quartz and a correspondingly larger proportion of plagioclase than those of the muscovite-bearing group.

As representatives of this group Plates II and III are given from sections of the granites from Dix island and Sullivan, Maine. These are both coarse, gray rocks, containing a considerable proportion of plagioclase in connection with the orthoclase. The biotite in thin sections is of a yellowish-brown color and bears numerous inclosures of apatite and magnetite. The pores in the quartz of these rocks are neither abundant nor large; in the Dix Island granite they are often arranged in fine wavy lines traversing the quartz grains in directions nearly parallel to one another.

The biotite granites from Manchester, Virginia, and vicinity are practically of the same constitution as these, although differing in details of texture. Small zircon crystals and scattering flakes of muscovite, together with a few garnets, are found in these rocks.

The granites of Westerly, Rhode Island, are biotitic, but differ from those just mentioned in being usually of a finer texture and more rich in accessory minerals, containing frequently small crystals of fluor-spar, sphene, menaccanite, magnetite, apatite, epidote, and pyrite; the quartz contains also many of the small, thread-like crystals so characteristic of rutile. Many of the Westerly granites are of a flesh-red color, but otherwise than this they do not differ materially from the ordinary gray granites, the red color being as usual due to the red orthoclase they contain.

The red granites quarried at Red Beach and at Jonesboro', Maine, have biotite as their characterizing accessory. These are coarse, compact rocks of even texture, and tough and hard. They bear but few accessory minerals, a little apatite and magnetite only being observed. The mica occurs usually in small ragged shreds of a greenish color.

The red granite quarried at Lyme station, Connecticut, differs from the last in being of a still coarser texture, and in the feldspars occurring in beautiful large glassy crystals. The proportion of plagioclase is much larger than in the Maine red granites, and it contains little if any apatite and magnetic iron. The quartz contains numerous quite large pores or cavities, in many of which moving bubbles were noticed, while in others the bubbles were motionless.

The Leetes Island and Stony Creek red granites are of a much lighter shade than those of Lyme, the feldspars being only light pink or flesh-red in color, and of a more gneissoid structure. Some muscovite is present, together with the biotite and a little epidote; the quartz contains but few cavities. A part of the Leetes Island rock has a porphyritic structure, and is of a mottled pink and gray color, due to the larger pink feldspar crystals being surrounded by a finer admixture of small grains of quartz and mica.

A coarse red granite is quarried in the vicinity of Iron Mountain, Missouri, a part of which differs from any of the preceding in containing no characterizing accessory, to the unaided eye the stone appearing to consist only of quartz and feldspar. Under the microscope a few grains of magnetite are visible, as well as a few scales of hematite. Other granite from this locality contains black mica, which is usually more or less altered into chlorite. A red granite comes from Burnet county, Texas, which is of a fine, even texture, and contains much plagioclase. So far as observed this stone is lacking in tenacity, but this is very probably due to the fact that the quarries have not yet been worked to sufficient depth to bring to light the better portions of the rock, the feldspars showing signs of decomposition such as are produced by weathering.

The red biotite granite from the government quarries at Platte cañon, Colorado, is much coarser than the last, and contains many blood-red scales of hematite. The biotite is very dark and opaque.

So far as observed, all our porphyritic granites are biotitic. A part of the East Bluehill (Maine) rock is a beautiful example of this variety. This is a fine dark-gray rock, the uniformity of whose texture is broken by a plentiful sprinkling of snow-white orthoclase crystals of an inch or more in length, the crystals being usually in the form of Carlsbad twins. In many of the East Bluehill rocks the biotite is found altered into a chlorite, in which case it contains numerous inclosures of magnetite. Muscovite is also frequently present in small quantity, together with the usual colorless apatite crystals.

MUSCOVITE-BIOTITE GRANITE.

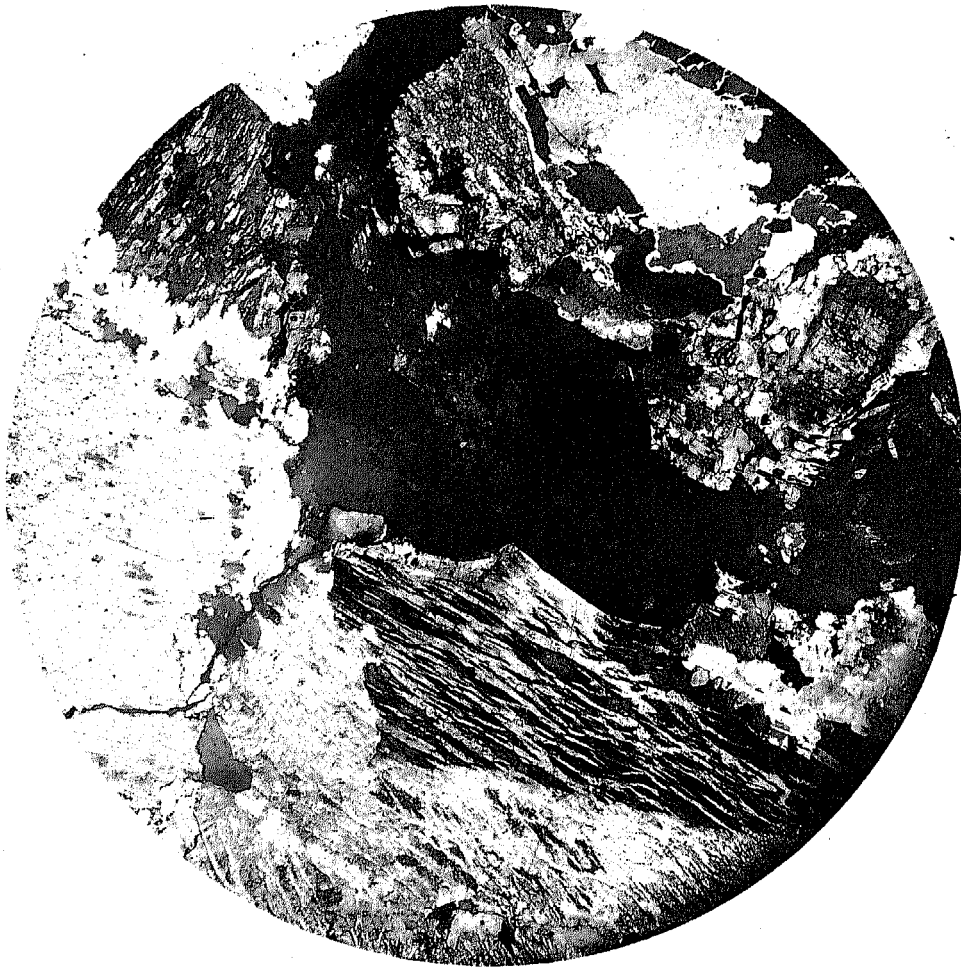
As its name denotes, this variety combines the properties of both muscovite and biotite granite, and may be considered as intermediate between the two. Transition stages between this and true muscovite or biotite granite are continually met with, and, as already stated, no sharp line of distinction can be drawn between them. The essential constituents are quartz, orthoclase, muscovite, and biotite; small transparent crystals of apatite are nearly always present, together with more or less plagioclase; zircons occur quite rarely.

Of this variety, the so-called Concord (New Hampshire) granite may be considered as typical. It is a fine-grained, light-gray rock, showing under the microscope a somewhat drusy structure. The feldspars are in nearly every case more or less turbid through decomposition and impurities, while the quartz is penetrated in every direction by small needle-like crystals of rutile. Fluidal cavities are quite small and not at all abundant. According to Dr. Hawes, (a) the plagioclase of this rock is oligoclase; some microcline is also present. The micas usually occur in small, irregular flakes, without definite crystalline outline, but occasionally a small, perfect crystal of muscovite can be seen.

Between the Concord and the lighter colored of the Fitzwilliam granites there is no essential difference. Microscopic particles of zircon were found in the Fitzwilliam rocks, which were not noticed in those of Concord.

The granites quarried at Allenstown, Sunapee, and Rumney offer no differences of practical value. As a general thing they are much like the Concord, presenting only slight variations in the way of color and texture. The feldspars as seen by the microscope are sometimes in a little fresher state and contain fewer impurities, while the quartz usually contains less rutile, that from Rumney having none at all, and fluid cavities are perhaps a trifle more

PLATE IV.



Hornblende Granite,
Peabody, Mass.

abundant. The Manchester granite differs from any of the preceding in being of coarser texture, with a flesh-red color, and containing very little biotite, but a much larger proportion of microcline. The quartz frequently contains small colorless crystals resembling fibrolite; brilliantly red scales of hematite are also occasionally met with, as well as many large opaque grains of magnetite.

Outside of New Hampshire, muscovite-biotite granite is quarried quite extensively at Ryegate, Vermont, and at North Jay, Lincolnville, and Hallowell, Maine. The Ryegate rock is of coarser, more even texture, and contains a larger proportion of quartz than that of Concord. The quartz is almost entirely free from rutile inclusions and the feldspars are in a very pure condition, in both of which respects it closely resembles the Jay rock. The Hallowell and Lincolnville granites resemble the Concord closely, both in color and in structural peculiarities, even to the presence of the rutile inclusions. It contains, however, a much larger proportion of the feldspar microcline. A few garnets unobserved elsewhere are present in the Hallowell rock.

A rather coarse biotite-muscovite granite is quarried near Fredericksburg, Virginia. The feldspars in this rock are quite impure and frequently contain numerous inclosures of muscovite. Microcline is quite abundant in this rock, as is the case also with that of Hallowell and Augusta, Maine.

HORNBLENDE GRANITE.

As has already been stated, no sharp lines of separation can be drawn between the different varieties of granite, and in no case is this better illustrated than in those rocks bearing hornblende as their chief accessory, nearly all of them containing more or less black mica. This is well illustrated in the case of the granite quarried at Gloucester, Rockport, Lynnfield, and other localities in Massachusetts. From specimens of these rocks forwarded to the Museum it appears that while with one or two exceptions they would, from a simple macroscopic examination, be classed as hornblende granites, the microscope shows a constant gradation from those in which biotite is easily distinguishable in the hand specimen to those in which apparently there is none, more or less mica appearing in all. The distinction must, therefore, be somewhat arbitrary, and only those have been called hornblende granites in which no biotite was visible to the naked eye. (a)

As typical of this group, Plate IV is given. It is from a magnified section of the rock quarried at Peabody, Massachusetts. This rock, which agrees so closely with that quarried at the other localities named that a single description will do for all, is a coarsely crystalline rock composed essentially of quartz, orthoclase, and hornblende, the orthoclase being frequently of a faint greenish or bluish tinge, while the quartz varies from light glassy to dark smoky tints. The rock is of quite uniform texture, exceedingly hard and tough, and may be ranked as one of our most durable granites. Under the microscope it is seen that the feldspar of this rock is nearly all orthoclase in a very fresh and undecomposed condition, and as orthoclase is the hardest and toughest of all the feldspars the predominance of this variety over all others easily explains the hardness of the rock. In none of the granites quarried during the census year are the plagioclasic feldspars entirely absent, though sometimes prevalent in very minute quantities, as is well illustrated in the hornblendic granites of Gloucester, Roxbury, Lynnfield, Peabody, etc., and especially in that of the last-named locality, where it exists only as minute microscopic crystals, filling the interspaces between the larger crystals of orthoclase. The quartz, which is quite abundant, contains the usual cavities, in some of which moving bubbles occur. The hornblende is of a deep green, almost bluish, color, and never occurs in perfect crystals, but rather in broken fragments and ragged shreds bearing numerous inclusions of apatite and zircon. Zircon is especially abundant in the Gloucester granites, where it occurs usually in small, square prisms scattered irregularly about or clustered around the ragged edges of the hornblende crystals. Some magnetite is usually present, and an occasional shred of black mica.

A very beautiful deep-red hornblendic granite is quarried at Otter creek, Mount Desert, Maine. It is a very compact rock, though not quite as tough as those from Cape Ann. Under the microscope the feldspar is found to be quite opaque through impurities. The hornblende is deep green, nearly black, and some chlorite and apatite are present, together with quite large epidote granules and a few zircon crystals.

Two varieties of hornblende granite, one red in color and the other gray, are quarried at Saint Cloud, Minnesota. They differ, however, from their Massachusetts representatives, being of more uneven texture and containing a larger proportion of hornblende. The hornblende, which is frequently much decomposed, is of a deep brown color in thin sections and strongly dichroic. It contains numerous inclusions, such as apatite, magnetite, and zircon, although these last are not as prevalent as in the Gloucester rock; some biotite is also present. The feldspar, as in the Massachusetts rock, is nearly all orthoclase, is quite impure and opaque, and the quartz contains many inclusions and cavities, some of which are quite large. Although of the same mineral constitution as the Cape Ann granites, these are of decidedly inferior quality, being softer and less tenacious. It is more than probable, however, that when the quarries have been worked to a sufficient depth a far better quality of rock will be produced.

a It is very probable that much of the black mica of our granites is not biotite, but lepidomelane or annite, these being the names given by Professors Dana and Cooke to the black mica of the Cape Ann granite. Such differ from biotite in containing sesquioxide of iron in place of the protoxide, and in being more opaque and less elastic. Their optical properties are, however, identical with biotite, and in the present work no such distinction has been deemed advisable. All black dichroic micas have, therefore, been called biotite. (See *Hawes' Min. and Lith. of N. H.*, p. 82.)

A coarse, red hornblendic granite is quarried at Grindstone island, New York, in which, however, the hornblende has undergone extensive alteration, and which contains so large an amount of calcite as to effervesce distinctly when treated with a dilute acid. A little mica is present, which is of a copper-red color in the thin section, and a few small apatite crystals, together with numerous crystals of zircon. The rock contains considerable pyrite, which may be easily observed on a polished surface of the stone as small specks of a yellow metallic luster. The quartz occurs only in very small grains grouped together in the interspaces between the feldspars.

HORNBLLENDE-BIOTITE GRANITE.

The rocks of this group stand intermediate between true hornblende and biotite granites, and combine to a certain extent the properties of both. The essential constituents are quartz, orthoclase, hornblende, and biotite, with the usual accessories. To this group belong some of our most beautiful granites. Plate V is from a magnified section of a granite of this class—the so-called black granite of Saint George, Maine, the black color being due to the abundance of hornblende and black mica. Under the microscope it is seen that the rock contains a small amount of quartz and a proportionately large amount of plagioclase, and that the hornblende predominates over the mica. The feldspars are very fresh in appearance, and the quartz contains but few cavities. Magnetite and pyrite are present, together with a little apatite. This rock also contains a very considerable amount of calcite, which must have an important bearing upon its weathering qualities. It is a very beautiful rock, acquiring a fine polish.

In this group must also be placed a part of the granite quarried at Cape Ann, Massachusetts, although the two rocks in general appearance are totally unlike, the Cape Ann rock being coarsely granular and of a slight greenish tinge due to the orthoclase, which is the prevailing constituent. Quartz is abundant, and the black mica and hornblende are in about equal proportions. Under the microscope the feldspar is found to be moderately pure, and but little plagioclase is present, the feldspar, as is usual in rocks rich in quartz, being nearly all orthoclase. Numerous quite large microscopic zircon crystals are found intermingled with the hornblende and mica.

A third hornblende-biotite-bearing rock is quarried at Sauk Rapids, Minnesota. This is a dark gray granite, of which the general uniformity of structure is interrupted by frequent black blotches of about the size of a pea, which are caused by segregation of mica. The feldspar is of a slightly pinkish tinge, and by the microscope is seen to be very impure and murky. The quartz contains very many inclusions and cavities. The general quality of the rock is much inferior in point of beauty to those previously mentioned.

EPIDOTE GRANITE.

Although very many of our granites bear epidote in small proportions, usually visible only with the aid of a microscope, the cases in which it is of sufficient abundance to give a specific character to the rock are rare, the epidotic granite quarried at Dedham, Massachusetts, being at present almost the sole representative. This is a fine, even-grained rock of a light pink color, spotted with small specks of light green, which are due to the included epidote crystals. Under the microscope the epidote appears usually in irregular grains of a faint yellowish-green color, and is but faintly pleochroic. A little biotite is present, which has in nearly every instance become altered into a green chloritic product. The feldspar of this rock is quite impure and opaque. Owing to its fine, even texture the rock works easily and takes a good polish. The granite quarried at Lebanon, New Hampshire, contains epidote in considerable quantity, a thin section under the microscope showing innumerable small, nearly colorless, crystals scattered throughout the mass of the rock. They usually occur in groups or clusters, and are the cause of the light green blotches seen on a polished surface of the rock.

SYENITE.

If in a granite the quartz is absent, or becomes so small in amount as to become a merely accessory constituent, the rock is called syenite.

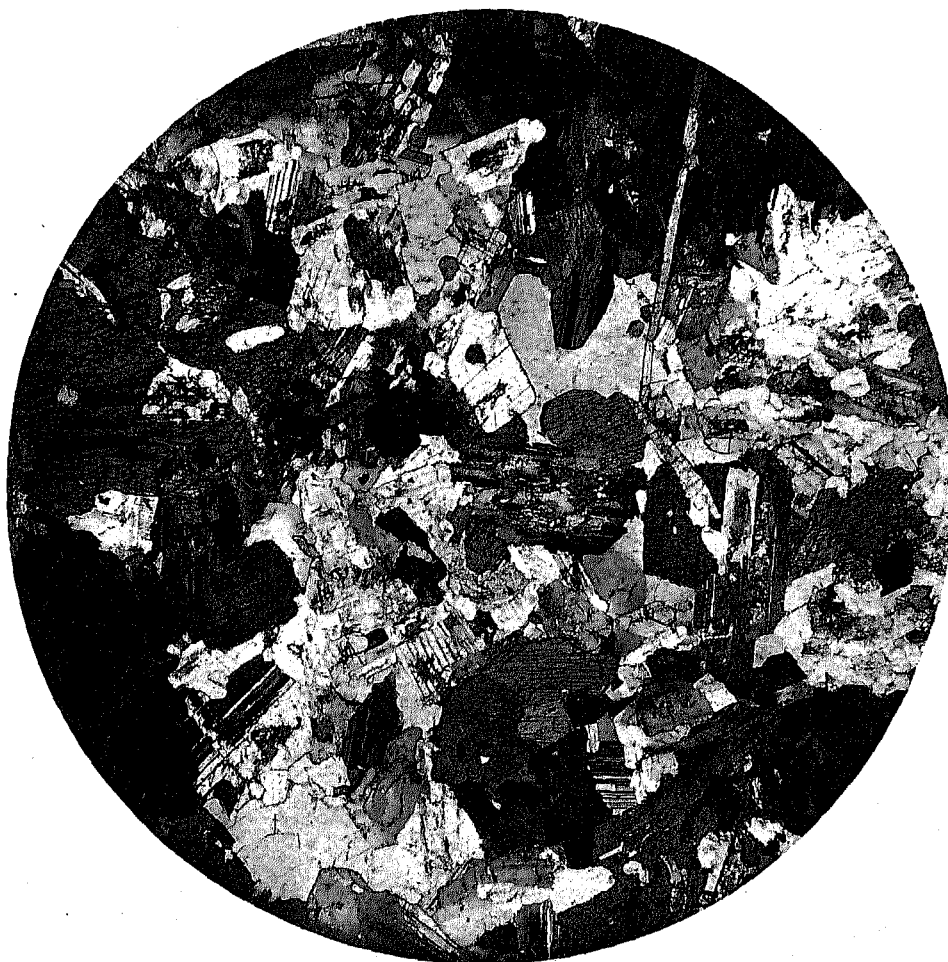
Syenite is quarried to a very small extent in the United States. In the system of classification there are just as many varieties of syenite as of granite which are characterized by the presence of the same accessory ingredients. Lithologically, many of these varieties are known to exist; mica syenites of the various kinds, hornblende syenites, augite or pyroxene syenites, and epidote syenites are all recognized; but none of the extensively-quarried building stones in the United States are syenites, although very beautiful rocks occur which would be much admired if they were introduced into the market.—G. W. H. (a)

GNEISS.

The gneisses or stratified granites are extensively quarried. Stratification is a circumstance very favorable to the extraction of stone for some purposes. For example, the perfection of cleavage in certain directions makes it easy to split large slabs from the mass, to be used for curbing, pavings, steps, etc. The stones can also be split in

^a This paragraph is from Dr. Hawes' notes.

PLATE V.



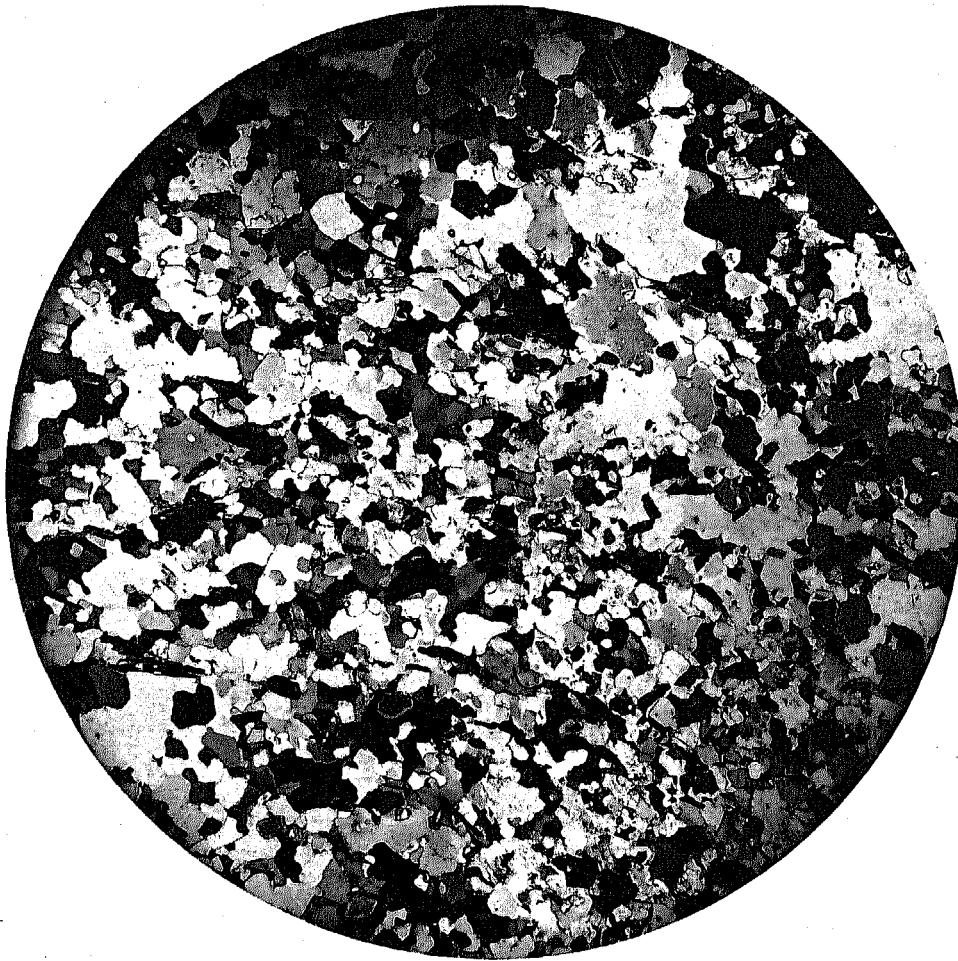
Hornblende Biotite Granite,
St. George, Me.

PLATE VI.



Hornblende Biotite Gneiss,
Middletown, Conn.

PLATE VII.



Mica Schist,
Washington, D. C.

such a way as to always possess two parallel flat surfaces, a circumstance which simplifies the construction of walls from them. The stratification is caused principally by the arrangement of the mica with its flat cleavage planes arranged in parallel directions.

Quartz and feldspar are again the essential constituents, and the same accessories constitute a series of gneisses identical with the granite series. We thus have biotite gneiss, muscovite gneiss, hornblende gneiss, pyroxene gneiss, etc.

There are no uses to which granite is applied to which the gneissoid rocks cannot also be applied; and some of the largest quarries in the United States which are called granite quarries really produce gneiss. In common nomenclature these rocks are called granite, or at best "bastard" granite or "stratified" granite, or granite with some other adjective prefixed. There is reason for this in the circumstance that they are used for the same purposes and very often have had the same origin, and differ from one another only in that some slight movement in the mass at the proper time gave a stratification to the rock. In certain cases also the stratification is very faintly evident, so that it is difficult to recognize as stratification. Indeed, there is no line of division between the granites and the gneisses when the structure alone is considered.

There are many gneissoid rocks which are very markedly stratified, which consist of alternate layers of very different compositions, and which were apparently deposited like the limestones and sandstones, and subsequently hardened and crystallized. Even in scientific classification it is now impossible to separate gneisses that have been deposited in stratified layers from those which have become stratified, as explained, by movements in a plastic mass. In this work there is no necessity for any distinction, and rocks of the composition of granite, but stratified in structure, will all be considered as gneisses, for, from the economic standpoint, structure is of more importance than questions as to the mode by which it was produced.

MICA-SCHIST.

Mica-schist is a rock that consists essentially of quartz and mica. It usually possesses a distinct schistose structure due to the parallel arrangement of the quartz and mica, as was noted in the gneisses, from which it may be said to differ only in its lack of feldspar. It is a rock which is supposed to have been formed by the deposition and subsequent crystallization of sediments, and consequently the structure of these minerals and their arrangement are markedly stratified. The peculiarities of the schists are not such as to render them favorites for purposes of fine construction. They are, however, broken out from the ledge with great comparative ease, and for rough construction, such as foundations and bridges, they are extensively employed.

The mica of the schists may be either biotite or muscovite, or both; in short, the schists may be characterized by one or more of the same accessories as are the granites and gneisses, and we may have just as many varieties. Through a diminution of the amount of mica these rocks pass into quartz-schists, and, by an increase of feldspar, into gneisses. The relative amounts of quartz and mica vary almost indefinitely. The percentage of silica, which is dependent largely upon the amount of quartz, varies from 40 to 80 per cent. The finer grained, more compact varieties of mica-schist make very fair building material, but the coarser varieties are not to be desired, especially if the mica be biotite and in great abundance.

In accessory minerals mica-schists are particularly rich. Some of the more common of these are garnet, feldspar, epidote, cyanite, hornblende, chlorite, staurolite, magnetite, pyrite, tourmaline, and rutile. Through an increase in the amount of hornblende or chlorite the rock frequently passes gradually into hornblende and chlorite schists.

As an illustration of the microscopic structure of a biotite schist, Plate VII is given. This is from a magnified section of the schist quarried in the vicinity of Washington, District of Columbia, and popularly called "Potomac blue-stone". As will be noticed, this rock consists almost wholly of quartz and biotite, the quartz being in irregular grains, while the mica occurs in ragged shreds. The prevailing schists throughout the vicinity are, however, by no means of so simple a structure.

As a general thing the District rocks are distinctly schistose, the mica laminae being arranged in parallel layers, and the rock consequently splitting easily in the direction of its schistosity. In some cases, however, the various mineral ingredients are so evenly commingled that all traces of schistosity are lost in small specimens, and the rocks, especially if they contain hornblende, more closely resemble basic rocks of eruptive origin, for which they have at times been mistaken.

Under the microscope the mica is seen to be frequently of a greenish color and to bear numerous inclosures of apatite, magnetite, and garnet. More or less white mica is frequently present, though never in sufficient abundance to give any distinctive character to the rock. Hornblende, when present, is usually in the form of slender rhombic prisms, which are often broken transversely. It is of a yellow or greenish-blue color, polarizing in deeper blue, or the lighter varieties in lively yellow and red, closely resembling augite. The crystals are quite imperfect, and are in many cases filled with inclosures of apatite, magnetite, and mica. It is frequently observed to have undergone an alteration into a greenish chloritic product.

One of the more abundant accessories in these schists is apatite. This occurs in small, perfect crystals which are nearly colorless in thin sections, though polarizing in faint yellow and bluish colors. The crystals are usually quite small, seldom exceeding 0.3^{mm} in length. Small, nearly transparent epidote crystals are also sometimes present, and quite often a triclinic feldspar, which is apparently oligoclase.

Another accessory of by no means so common occurrence, though quite abundant in some of these schists, is rutile. This occurs in the form of minute four- and eight-sided prisms, seldom more than one or two millimeters in length, and of a deep brownish-red color. Very small crystals are frequently found grouped together in nests of half a dozen or more, but the larger ones are always single and scattering. Geniculate forms, so characteristic of rutile, are met with but rarely. Their striking color renders them especially noticeable in spite of their small size.

Garnets are quite abundant, nearly every section showing one or more, and frequently they are so large as to be visible without the aid of the microscope. They are of rounded or irregular form, seldom with a perfect crystalline outline, and of a delicate salmon color, as seen in the section. They are sometimes quite pure, but many contain numerous inclosures of a black, opaque substance, which is probably magnetite, and also numerous quartz grains.

An accessory of more practical importance than any yet mentioned is the bisulphide of iron, or iron pyrites, which is only too abundant in much of this rock, occurring in cubical crystals and irregular grains of a brassy-yellow color and often of considerable size. On weathering, the pyrites oxidizes and disappears, but leaves its characteristic stain behind, and frequently produces the more serious result of disintegration.

DIABASE.

Under the term diabase is included a majority of the rocks commonly known as trap-rock and black granite. They consist essentially of augite and a triclinic feldspar, which is usually labradorite, though oligoclase and anorthite are not uncommon. As microscopic accessories they nearly always contain magnetite, titanite iron, and frequently apatite and black mica; hornblende and chlorite are not rare as products of alteration, a process to which these rocks, owing to their basic nature, are extremely liable. In texture the diabases are usually too fine to allow a determination of their mineral constituents with the naked eye, although porphyritic varieties are not rare. The color varies from dark gray to nearly black or greenish, according to the varying proportions of the different constituents.

These rocks are frequently called by the quarrymen and others black granite, although, as will be noticed, they differ from granite most decidedly, in containing no quartz, and in the feldspars being all triclinic; orthoclase, which is usually the predominating ingredient in the granites, being here entirely wanting. They are basic eruptive rocks of ante-Tertiary origin, and generally occur in well-defined dikes, cutting the surrounding formations in a manner very noticeable even to the most careless observer.

Plate VIII is from a magnified section of the diabase quarried at Weehawken, New Jersey. Identical (practically) with this are the trap-rocks quarried at various localities in New Jersey, Pennsylvania, and Virginia; and a similar rock, but of finer texture, comes from New Haven, Connecticut. The diabase quarried at Medford, Massachusetts, differs from those just mentioned in being of much coarser texture and in containing a pinkish feldspar and an abundance of black mica. An abundance of apatite is also present, and considerable chlorite. The feldspars in this rock are much decomposed, frequently so much so as to be almost unrecognizable. A micaceous diabase is also quarried under the name of black granite at Addison, Maine. This rock has a very complex structure. Besides mica, considerable hornblende is present, which results from the alteration of the augite, it being not infrequent to find a crystal the boundaries of which are unmistakably hornblende, while the center is still unaltered augite. A very similar rock, but containing olivine, is found at Indian River, Addison township, Maine. Olivine, however, is a mineral of very unstable composition, and is rarely found in an unchanged condition. In the present case almost the entire mineral has become changed to a serpentinous product, leaving but a small portion of the original substance near the center of the crystal still unaltered. Both of these diabases contain two varieties of plagioclase, and in addition to the minerals already named there are present chlorite, biotite, apatite, magnetite, and titanite iron, the last named being usually much decomposed and taking on very fantastic forms. A section of this rock is given on Plate IX.

An olivine-bearing diabase is also quarried at Vinal Haven, Maine, though in this case the olivine is much less altered than in the Addison rock. A little chlorite is present, and some biotite, but the composition of the rock is much less complex than is that of the stone from Addison.

BASALT.

True basalt is but little used for building purposes. Like diabase, it consists essentially of a triclinic feldspar, augite, and titanite iron or magnetite, or both. Olivine is also almost invariably present, while nepheline, leucite, hauyne, apatite, and mica are common accessories. It differs, however, from diabase in being usually of finer texture, and of more recent origin.

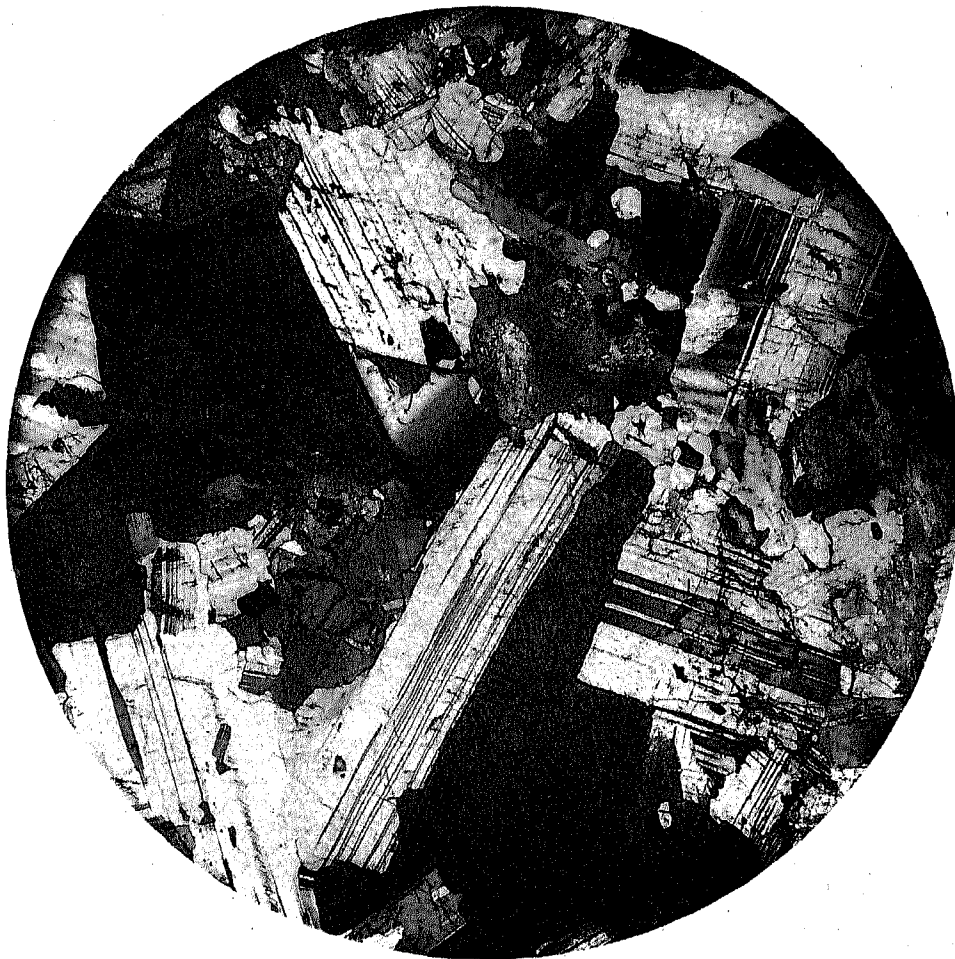
Of the same composition as diabase we would naturally expect to find the included minerals undergoing the same processes of alteration, which is often the case. Calcite, zeolites, chalcedony, and carbonate of iron often

PLATE VIII.



Diabase,
Weehawken, N. J.

PLATE IX.



Olivine Diabase,

Addison, Me.

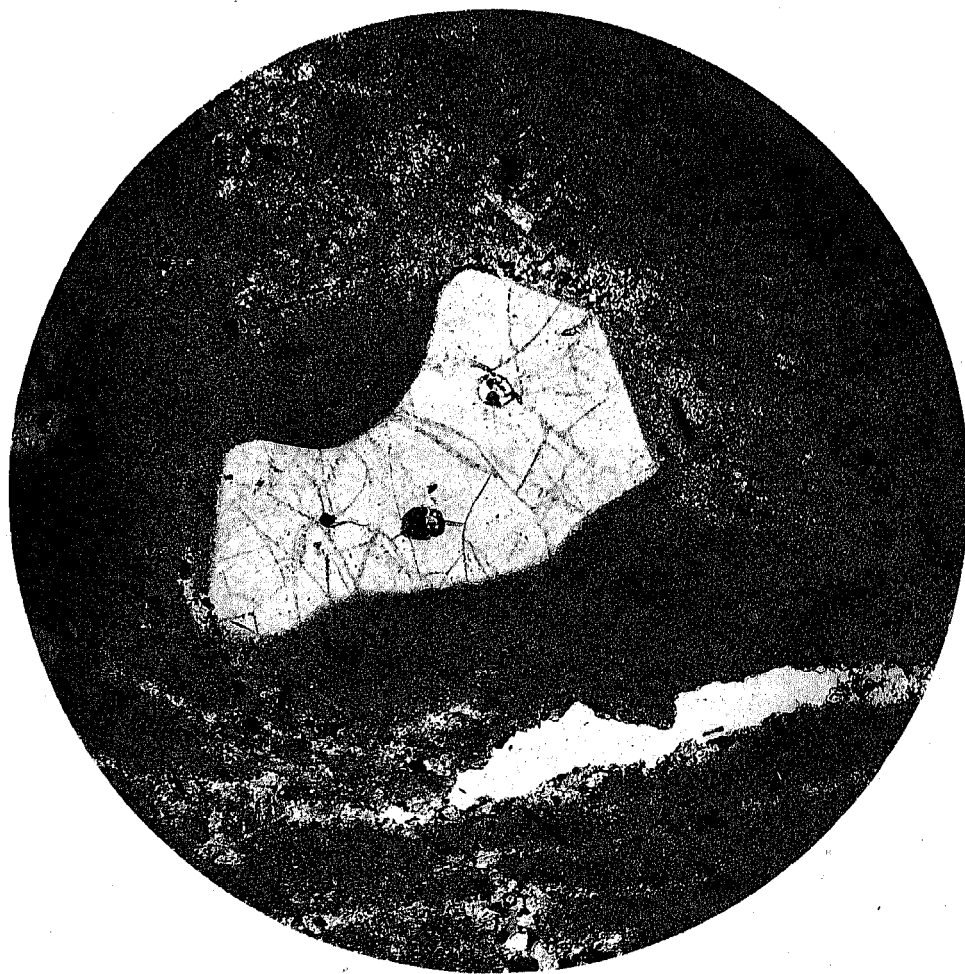
PLATE X.



Basalt,

Bridgeport, Cal.

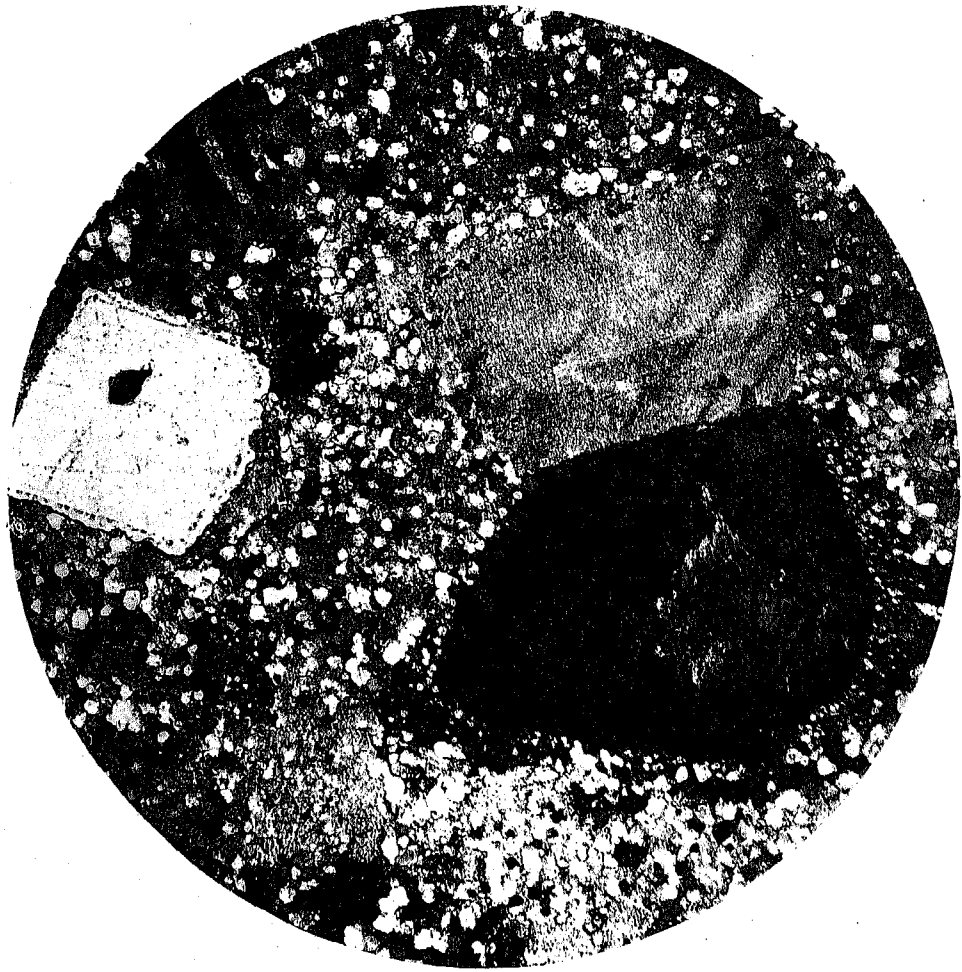
PLATE XI.



Quartz Porphyry,

Fairfield, Pa.

PLATE XII.



Orthoclase Porphyry,

Stone Mountain, Mo.

occur as secondary products, lining the walls of the small cavities or amygdulæ with which the rock is frequently filled. The feldspar of basalt can be either oligoclase, andesite, anorthite, or labradorite, and it is usually the prevailing ingredient; the spaces between the individual crystals are frequently filled with an uncrystalline, glassy magma, containing often numerous opaque, elongated, hair-like bodies, called "trichites".

Microscopic sections of basalt present many interesting features. The plagioclase usually occurs in small, slender crystals, showing in polarized light the customary banded structure, due to twinning. It is usually quite pure and free from all inclusions or cavities. The olivine appears rarely in well-defined crystals, but rather in rounded grains, traversed by many irregular curvilinear lines. They are sometimes of considerable size, so as to be easily distinguished by the naked eye. The augite in basalts is generally rich in inclosures of glassy matter, and in rocks which have undergone considerable decomposition both the augite and olivine are often represented merely by pseudomorphs of a green matter, either serpentine or some other hydrous silicate. Plate X is from a basalt quarried at Bridgeport, California. This is a fine-grained, brownish-gray rock, in which the included olivine crystals appear as small, greenish, rounded grains, often the size of a pin's head, scattered throughout the fine gray ground mass, the separate ingredients of which cannot be detected by the unaided eye. In the plate they appear as large, rounded, dark grains, surrounded by the smaller crystals of augite and plagioclase, like islands around which the semi-fluid mass has flowed.

PORPHYRY (PORPHYRITIC FELSITE).

Under the term porphyry it is usual to include a class of fine-grained, compact, felsitic rocks, the composition of which is not determinable by the naked eye, owing to the minuteness of the constituent minerals. The rocks consist essentially of quartz and orthoclase feldspar, one or both of which substances is frequently, though not always, present in crystals of considerable size, which lie embedded in the close, compact ground mass.

Under the microscope these rocks, as represented by the building-stone collection, can be divided into two classes, (1) those in which the ground mass is easily resolved into a crystalline aggregate of quartz and feldspar grains, and (2) those in which the ground mass gives between crossed Nicol prisms the polarization colors of an aggregate, which, even by high powers, cannot be resolved into its constituent minerals, owing to their minuteness. In both classes larger crystals of either quartz or orthoclase may or may not be developed to give rise to the well-known structure called porphyritic. According to which of these minerals is thus developed we have two kinds of porphyry—quartz porphyry and orthoclase porphyry. These two varieties are shown on Plates XI and XII. Plate XI is a quartz porphyry from Fairfield, Pennsylvania. The large white body in the center of the field is quartz, while the surrounding material is an intimate mixture of the same mineral and feldspar, but in so finely divided a state as to be inseparable by even the highest powers. Plate XII is of an orthoclase porphyry from Stone Mountain, Missouri. In this rock it will be noticed that the ground mass is distinctly granular, and the porphyritic structure is due to large crystals of orthoclase, in place of the quartz as in the preceding. Both rocks are much alike in general appearance, although differing so decidedly in microscopic structure.

Porphyries are usually of eruptive origin, occurring in dikes, after the manner of what are popularly called trap-rocks. The well-known porphyries in the vicinity of Boston are, however, according to some authorities, metamorphosed sedimentary deposits. (*a*)

Porphyries present considerable variation in color; whitish, flesh-colored, red, blue-black, black, and green are common varieties. They are very close-grained, compact rocks, and take an excellent polish. They are also almost indestructible, withstanding for ages the effects of weathering without appreciable change. Their hardness and lack of stratification, however, are great drawbacks to their extensive use, since they can be taken from the quarries only in small, very irregular blocks, and are cut with extreme difficulty. They are at present but little used for building purposes in this country. In Great Britain they are used chiefly for causeway stones and road metal, for which their hardness and toughness render them especially suitable.

SANDSTONES.

Sandstones are composed principally of rounded and angular grains of sand that have become cemented together through the aid of heat and pressure, forming a solid rock. The cementing material may be either silica, carbonate of lime, or an iron oxide. Upon the character of this cementing material is dependent to a considerable extent the color of the rock and its adaptability to architectural purposes. If silica alone is present the rock is light colored, and frequently so intensely hard that it can be worked only with great difficulty. Such stones are among the most durable of all rocks, but their light colors and poor working qualities are something of a drawback to their extensive use. The cutting of such stones often subjects the workmen to serious inconvenience on account of a sharp and very fine dust or powder made by the tools, and which is so light as to remain suspended for some time in the air. The hard Potsdam sandstones of New York state have been the subject of complaint on this score. Professor

a T. T. Bouvé, *Proc. of Boston Soc. of Nat. History*, 1862, p. 57; 1876, p. 217.

Geike, in writing on the decay of rocks, (a) mentions an instance in which a fine siliceous sandstone, erected as a tombstone in an English church-yard in 1662, and afterward defaced by order of the government, had retained the marks of the defacing chisel upon its polished surface perfectly distinct after a lapse of over two hundred years.

On the other hand, those rocks in which carbonate of lime is the cementing material, although soft enough to work well, are frequently too soft and crumble easily, beside disintegrating rapidly when exposed to the weather. On many accounts the rocks containing the ferruginous cement are preferable, since they are neither too hard to work readily nor are they liable to so unfavorable alteration when exposed to atmospheric agencies. These rocks also have a brown or reddish color, which is usually considered as something in their favor. The celebrated Portland brownstone, used so extensively for building purposes in New York city, is a good representative of this variety.

Sandstones are of a great variety of colors; light gray (almost white), gray, buff, drab or blue, light brown, brown, and red are common varieties, and, as already stated, the color is largely due to the iron contained by them. According to Mr. G. Man (b) the red and brownish-red colors are due to the presence of iron in the anhydrous sesquioxide state; the yellow color to iron in the hydrous sesquioxide state, and the blue and gray tints to the carbonate or the protoxide of iron. It is also stated that the blue color is caused sometimes by finely-disseminated iron pyrites, and rarely by an iron phosphate. (c)

In texture sandstones vary widely, from an almost impalpable fine-grained stone to one in which the individual grains are the size of a pea. The looser varieties, in which the grains sometimes reach an inch or more in diameter, are called conglomerates, or if the pebbles are angular instead of rounded, a breccia.

Sandstones are not always composed wholly of quartz grains, but frequently contain a variety of minerals. The brown sandstones from Connecticut, New Jersey, and Pennsylvania are found on microscopic and chemical examination to contain one or more kinds of feldspar and frequently mica, (d) having in fact the same composition as granite or gneiss, from which they were doubtless originally derived. According to Dr. P. Schweitzer, (e) a fine-grained sandstone from the so-called palisade range in New Jersey contains from 30 to 60 per cent. of the feldspar albite. That quarried at Newark contains, according to his analyses, albite 50.46 per cent., quartz 45.49 per cent., soluble silica 0.30 per cent., bases soluble in hydrochloric acid 2.19 per cent., and water 1.14 per cent. This, however, must be regarded as an exceptional case, as very many sandstones contain no feldspar at all, being probably derived from a quartzose rather than from a granitic rock. Some sandstones are thought to originate from chemical deposition rather than from the disintegration of pre-existing rocks. Certain of the crystalline sandstones of Ohio are of this class. (f)

The minute cavities and moving bubbles so frequently seen in the quartz grains of granite are, as would naturally be expected, also occasionally found in sandstone, as is well shown in a white Potsdam sandstone quarried at Fort Ann, in the state of New York. The cavities in this case are extremely small, but the imprisoned bubble, as it glides unceasingly from side to side of its minute chamber, is readily seen with a microscope of high magnifying power.

Iron pyrites is a common ingredient of many sandstones, occurring frequently in cubical crystals or irregular grains of considerable size, and of a brassy-yellow color. Unless quite abundant, however, the chief danger to be apprehended from the use of such stone is the change of color it undergoes through the oxidation of the pyrites, which causes rust-colored or dark stains to appear wherever it exists. The beauty of many fine buildings has been sadly marred through the discoloration of the stone used for cappings and cornices by the oxidation of the included pyrites. Stone for such purposes should be subjected to careful examination, and all pieces in which the pyrites occur promptly rejected.

Nearly all sandstones are more or less porous, and hence permeable to a certain extent by water and moisture. Manifestly, then, in localities subject to any extremes of temperature, only those stones in which this porosity is reduced to the minimum should be used for buildings, since disintegration must certainly result if, after the pores of a stone become filled with water, freezing ensues. It is on account of the destructive effects of freezing water that such porous limestones as those of Bermuda and of Florida are totally unfit for use in countries in which the temperature falls frequently below the freezing point, although very durable in warmer climates. All sandstones absorb water most readily in the direction of their lamination or grain. It therefore follows, as every stonemason knows, that stone to weather well should be laid with its bedding (lamination) horizontal, as it was first laid down by nature in the quarry; the stone will also offer the greatest amount of resistance to pressure if laid in this manner, and, it is said, will stand a greater amount of heat without disintegrating; an important fact in cities, where any building is liable to have its walls highly heated by neighboring burning structures. The porosity of some sandstones is characteristically shown by their manner of drying after a rain; some will dry very quickly, while others containing a larger amount of water in their pores will remain moist a long time. Ordinary sandstones will absorb from 3 to

a *Geological Sketches at Home and Abroad*, p. 87.

b *Quarterly Journal of the Geological Soc.*, xxiv, p. 355.

c *Notes on Building Construction*, Part III (South Kensington series), p. 35.

d See Plates XIII and XIV.

e *American Chemist*, July, 1871, p. 23.

f J. Brainard, *Proc. Am. Soc.*, 1860.

PLATE XIII.



Sandstone,
Portland, Conn.

PLATE XIV.



Siliceous Sandstone,

Potsdam, N. Y.

PLATE XVI.



Quartz Schist,
Berks Co., Penna.

10 per cent., by weight, of water in 24 hours. Stone weighing less than 130 pounds per cubic foot and absorbing more than 5 per cent. of its weight of water in 24 hours, and effervescing somewhat actively with acid, is likely to be a second-class stone as regards durability. (a)

Some stones liable to the destructive effects of frost on first being taken from the quarries are no longer so after having been exposed for some time to the air, having lost their quarry water through evaporation. This difference is very manifest between stones quarried in summer and those quarried in winter. It frequently happens that stones of very good quality are entirely ruined by hard freezing immediately after being taken from the quarry (this being particularly the case with some marbles and limestones), while if they are quarried during the warm season of the year and have an opportunity to lose their quarry water by evaporation prior to cold weather they withstand freezing perfectly well. This phenomenon is easily accounted for if we admit the claim put forward by some that the quarry water of these stones carries in solution carbonate of lime and silica, which is deposited in the cavities of the rock as evaporation proceeds, thus furnishing additional cementing material and rendering the rock more compact. This will also account for the remarkable hardening of some stones after being quarried a short time, long since noted by those engaged upon stone work. When first quarried they are so soft as to be easily sawed and worked into any desirable shape, but after the evaporation of their quarry water they become hard and very durable. (b)

Conglomerate differs from sandstone only in point of structure, being coarser and of more uneven texture. This structure is well illustrated in Plate XV, which is from a magnified section of a conglomerate from Estelville, New Jersey. The large white grains are of silica and the dark cementing material is an iron oxide. These rocks are but little used for building purposes.

Quartzite is a hard, siliceous sandstone occurring in regions of metamorphic rock, and partially metamorphosed. It differs from ordinary sandstone in being harder and less friable. It sometimes possesses a well-defined schistose structure. Plate XVI is from a magnified section of a schistose quartzite from Berks county, Pennsylvania. Such rocks are very hard and compact, and would make very desirable building material.

LIMESTONES AND MARBLES.

Limestones consist essentially of carbonate of lime, though they are often more or less impure through the presence of organic matter and clay. It is usual to apply the name marble to those limestones that are highly crystalline in structure and susceptible of taking a good polish. The term is, however, very loosely applied, being sometimes made to include even siliceous crystalline rocks like granite. Limestones are mainly of organic origin; that is, they result from the deposition of organic remains, as shells, corals, etc. In many limestones these remains are still plainly evident, while in others they have become almost or entirely obliterated through metamorphism. The shell and coral limestones of Florida and of Bermuda are good examples of the first kind. In these the broken and water-worn fragments are simply cemented together by the same material in a more finely divided state without a trace of crystalline structure; and from these to a perfectly crystalline marble, without a trace of fossil remains, there is a constant gradation. The red-mottled and black marbles of Tennessee and of Isle La Motte, Vermont, are good examples of the semi-crystalline varieties. In these the microscope shows very plainly the remains of minute organisms, while at the same time the surrounding portions of the rock are crystalline. The oolitic limestones used so extensively for building purposes in Kentucky, Indiana, and Iowa are composed of the rounded grains of shells and corals closely cemented, and forming a very durable stone. They are generally quite soft and easily worked when first quarried, but become harder by exposure. The size of the individual grains is usually about that of a fish-egg, though they sometimes are larger, reaching the size of a small pea, when the stone is called pisolite. Some limestones are scarcely at all crystalline, nor do they show any trace of organic remains, but are perfectly homogeneous throughout. The stones quarried at Huntingdon, Pennsylvania, and at Kokomo, Illinois, are good examples of this variety. These stones are sometimes quite easy to work, though, being dull in color and not capable of receiving a good polish, they are not very desirable. They are usually very impure through the presence of clay and earthy matter.

Of the perfectly crystalline limestones, the white and the blue marbles quarried so extensively at Sutherland Falls and Rutland, Vermont, are the best examples. These are supposed to have been originally common fossiliferous limestones, and to have become crystalline and had all their fossils obliterated through the aid of heat and pressure. In some of these marbles the process of metamorphism was incomplete, and the traces of fossils still remain. According to some authorities (c) many limestones result not from fossil remains of animals, but from chemical precipitates from sea-water.

a *Notes on Building Construction*, South Kensington series, Part III, p. 36.

b *See Chateau*, Vol. I, p. 265.

c T. S. Hunt, *Chemical and Geological Essays*, pp. 82 and 311.

The white crystalline marbles vary greatly in texture, the finest being found in Vermont, and coarser varieties farther south and west. According to Dana (a) the texture is less coarsely crystalline in Vermont than in Massachusetts, the crystallization of the limestone as well as of associated schists increasing in coarseness from north to south, or rather southwest, which is the trend of the limestone belt. The whitest marble of Rutland is not as firm as that mottled with gray, owing apparently to the fact that it was made white by the heat that crystallized it burning out any carbonaceous matter, while at Pittsford, 16 miles to the north of Rutland, it is very firm, and is white, probably because it was made with less heat from a whiter limestone.

Statuary marble is a pure white crystalline marble of very even texture; it is sometimes called saccharoidal, from the resemblance of its grain to that of pure loaf-sugar. Ophiolite or verd-antique is a mixture of limestone and serpentine, as will be noticed further on.

Carbonate of magnesia is a common ingredient of many limestones in varying proportions, and such stones are called magnesian limestones. When, however, the substances are present in the proportion of 54.35 parts of calcium carbonate to 45.65 parts of carbonate of magnesia, the stone is no longer called a limestone, but a dolomite. These stones are highly valued for building purposes, and "the best varieties are those in which there is at least 40 per cent. of carbonate of magnesia with 4 or 5 per cent. of silica". The nearer a magnesian limestone approaches a dolomite in constitution, the more durable it is likely to be.

It is not merely the nature of the constituents or their mechanical mixture that gives dolomite its good qualities; there is some peculiarity in the crystallization which is all important.

In the formation of dolomites, some peculiar combination takes place between the molecules of each substance; they possess some inherent power by which the invisible or minutest particles intermix or unite with each other so intimately as to be inseparable by mechanical means. On examining with a highly magnifying power a specimen of genuine magnesian limestone * * * it will be found not composed of two sorts of crystals, some formed of carbonate of lime and others of carbonate of magnesia, but the entire mass of stone is made up of rhomboids, each of which contains both the earths homogeneously crystallized together. When this is the case, we know by practical observation that the stone is extremely durable. (b)

The impurities in limestones are numerous. Many contain sand, which greatly injures their weathering properties; others contain clay and earthy matter, which are also elements of weakness, since they possess no strength in themselves, and, in addition, absorb water with the greatest ease, which renders the stone more liable to disintegration by freezing. Iron pyrites is a common impurity of many limestones, and such are to be avoided. Many of the Pennsylvania marbles contain talc or mica. A beautiful, coarse, rose-red marble from Danville, New Jersey, contains an abundance of black mica, which occurs in small hexagonal crystals. A limestone in the vicinity of Chicago, Illinois, contains petroleum to such an extent that blocks of it which have been used for building, become discolored by its exudation after a short exposure to the air, and this becoming mixed with the dust of the air forms a very unsightly tarry coating on the surface of the stone. "This rock, though porous and discolored by petroleum, is, when freed from this substance, a nearly white, granular, crystalline, and very pure dolomite, yielding 54.6 per cent. of carbonate of lime." (c) This oil is not always noticeable at first, but its presence can easily be detected by the well-known odor of petroleum which a sample of the rock gives off when struck with a hammer.

Oxide of iron is a common ingredient of many limestones, and to this substance is due the red color of the Tennessee, Mallett's Bay, and other red marbles. The blue or black color so common in limestones and marbles is due to carbonaceous matter derived from the decomposition of plants and animals in the waters in which the stones were originally deposited. Its carbonaceous nature is made very evident when the stone is subject to a high temperature by its becoming pure white through the burning out of this substance.

Limestones and marbles, owing to their beautiful colors and the ease with which they may be worked, are much esteemed for building and monumental work. They are not, however, the most durable of rocks, especially in cities where the air contains any considerable amount of carbonic, sulphuric, or chlorhydric acid, since these, even in very small amounts, readily attack the surface of the rock and cause it to crumble. A great deal naturally depends upon the texture of the stone. The most durable are those which are compact and homogeneous in structure and composition and not too coarsely crystalline. As a general thing the blue and gray colors denote a more durable rock than the pure white, for reasons already noted.

Limestones weigh from 112 to 185 pounds per cubic foot, the lighter weight being that of a shell limestone from Saint Augustine, Florida, and the heavier a compact, fossiliferous, semi-crystalline rock from Doughertyville, Tennessee. As would naturally be supposed, the heavier stone is much the more durable, being more compact and therefore less liable to injurious atmospheric influences. But few experiments have been made in this country upon the absorptive properties of stones, but according to the results of various experiments made in England, limestones vary in the amount of water they will absorb from 1 to 12 per cent., by weight, in 24 hours. The microscopic structure of a crystalline white marble from Rutland, Vermont, is shown on Plate XVII.

a *Manual of Mineralogy and Lithology*, p. 433.

b *Notes on Building Construction*, South Kensington series, Part III, p. 58.

c T. S. Hunt, *Chemical and Geological Essays*, p. 172.

PLATE XVII.



Marble,
Rutland, Vt.

PLATE XVIII.



Serpentine,
Chester Co., Penna.

SERPENTINE.

Serpentine is essentially a hydrous silicate of magnesia, consisting, when pure, of nearly equal proportions of silica and magnesia, with some 12 or 13 per cent. of water. The massive varieties used for architectural purposes are, however, always more or less impure, containing frequently from 10 to 12 per cent. of iron protoxide, together with small amounts of chrome iron, iron pyrites, clayey matter, and the carbonates of lime and magnesia. It is a tough, compact rock of quite variable color, usually greenish, though sometimes yellow, yellowish-green, brownish-green, or, more rarely, red, its colors depending, according to Delesse, (*a*) upon the degree of oxidation undergone by the included ferruginous material.

The origin of serpentinous rocks has been a matter of considerable dispute. Formerly they were supposed to be eruptive, but later investigations have tended to show that this is not the case, but that they result from the metamorphism of magnesian sediments, (*b*) or from the decomposition or alteration of gabbro, diorite, and other hornblendic rocks, or from rocks rich in olivine, as lherzolite. We have already noted the extent to which the olivine in the diabase of Indian River, Maine, had become altered into a serpentinous product, and it is hence easy to understand how large masses might be derived from the alteration of rocks in which olivine was the prevailing ingredient. Plate XVIII is from a magnified section of the impure serpentine from Chester county, Pennsylvania. It is a fine-grained, porous, dull green rock, and so soft as to be easily cut with a knife. In thin sections under the microscope it is of a faint yellowish-green color, showing in polarized light a somewhat fibrous structure, the fibers forming an irregular network, the interspaces of which are filled in many cases with calcite. Many black grains are present, which in some cases are magnetite and in others chromite; the chromite usually occurs in small black kernels, which are quite opaque, or at best but faintly translucent upon the thin edges, where they show a faint reddish color. It is strongly magnetic; the magnetite is distinguished from the chromite by its entire opacity and its metallic blue luster as seen by reflected light.

Serpentine is sufficiently soft to be easily carved into any desirable shape, and can be readily turned on a lathe. It acquires a good polish, and is one of our most beautiful stones for mantels, table-tops, and all manner of indoor work. For outdoor work the polished stone is entirely unsuited, since when exposed to atmospheric influences, especially in cities, it soon loses its gloss, and, the surface weathering unevenly, it soon becomes as unsightly as it was once beautiful. Verd-antique is a marble or limestone through which green or yellowish veins of serpentine are disseminated. According to Hunt (*c*) the verd-antique marble of Roxbury, Vermont, is a mixture of serpentine with talc and a ferriferous carbonate of magnesia.

a Zirkel, *Petrography*, Vol. I, p. 320.

b T. S. Hunt on Ophiolites, *Am. Jour. Sci.*, Vol. XXIII, p. 239; also *Chemical and Geological Essays*, p. 317.

c *Silliman's Journal*, 2d, xxv, p. 226.